

AN INVESTIGATION OF THE EFFECTS
OF PULSATING CHARGING CURRENT
ON THE PERFORMANCE OF LEAD-ACID
STORAGE CELLS

CARVEL HALL BLAIR
AND
CHARLES EUGENE DONALDSON, III

1953

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By

Garvel Hall Blair

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Lieutenant, United States Navy

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Submitted in partial fulfillment of the
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in

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This work is accepted as fulfilling the
thesis requirements for the degree of

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ELECTRICAL ENGINEERING

from the

United States Naval Postgraduate School

PREFACE

The experiment discussed in this report was carried on from September, 1952, to May, 1953, at the U. S. Naval Postgraduate School, Monterey, California. The work was done in partial fulfillment of the requirements for the degree of Master of Science and in a desire to improve submarine storage battery performance. The investigators are grateful for the encouragement of Professor Allen E. Vivell and the technical assistance of Mr. Harold Schauer.

Carvel Hall Blair

Charles Eugene Donaldson, III

Monterey, California

May, 1953

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TABLE OF SYMBOLS AND ABBREVIATIONS

A -	Gross sectional area of gas collecting vessel.
°C -	Degrees Centigrade.
cps -	Cycles per second.
°F -	Degrees Fahrenheit.
F -	Fisher's statistical variable; Faraday's constant.
h -	Height of water in gas collecting vessel.
I -	Current.
KVA -	Kilo-volt amperes.
KW -	Kilowatts.
n -	Number of observations.
Q -	Charge, in ampere-hours.
R -	Gas constant.
r -	Virtual cell resistance.
s ₂ -	Sample standard deviation.
s -	Sample variance.
T -	Temperature.
t -	Time.
V -	Volume of saturated gas at 27°C., atmospheric pressure.
V' -	Uncorrected volume of gas.
W -	Energy in watt-hours.
X -	Sample mean.
η -	Efficiency.
θ -	Dacos' time fraction.
μ -	Population mean.
σ -	Population standard deviation.
σ ² -	Population variance.

Subscripts:

a -	Pertaining to total charge.
d -	Pertaining to discharge.
f -	Pertaining to finishing rate charge.
m -	Mean.
s -	Pertaining to starting rate charge.

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SUMMARY

Objective: An investigation of the effects of charging lead-acid storage cells with a pulsating direct current.

General Methods: A charging circuit was designed and constructed to permit charging a battery of three 24-ampere-hour cells with a pulsating direct current, carefully regulated and metered at 2.4 amperes average value, at a frequency variable from 0.2 to 400 cycles per second. The battery was repeatedly cycled under similar conditions except for frequency of the finishing rate charging current, which was varied from 0.5 to 400 cycles. Control charges, with a steady, non-pulsating current, were also conducted. The gas generation, ampere-hour efficiency, and watt-hour efficiency were determined for each charge, and an attempt was made to correlate these with frequency.

Findings: The investigators demonstrated qualitatively that charging a battery with pulsating current improved performance. For Willard ER-24-2 cells, the best results were observed at a frequency of about 0.5 to 1.0 cycles per second. Further tests, employing statistical methods, are necessary to find the reason for this improvement and to determine quantitatively its magnitude.

CHAPTER I

PREVIOUS INVESTIGATIONS

An investigation of the effects of a pulsating battery-charging current leads the experimenter into almost virgin territory. The pioneer in the field is F. Dacos of the University of Liège, who summarized his findings in the Revue Universelle des Mines. [3] His experiments compared generator charging of lead-acid cells to rectifier charging. (In a letter to the investigators Dacos stated that he used a 50 cycle per second current and an unfiltered, full-wave dry rectifier.) He concluded that charging with a pulsating current produced "remarkably better" performance than charging with a steady current. In particular, pulsing the current caused:

- (1) Higher efficiencies, both watt-hour and ampere-hour;
- (2) Decreased gassing (by an average of 18% in 100 tests);
- (3) Higher mean voltage on discharge;
- (4) Decreased "shedding" of active material; and
- (5) Increased cell life (by 34% in a single longevity test).
- (6) *Decreased consumption of water.*

Dacos found the shape of the current pulses to be relatively unimportant.

His brief, qualitative explanation of these phenomena will be discussed later in this paper.

The literature revealed no other reference to battery performance as affected by pulsating charging current, even in Vinal's authoritative Storage Batteries [12]. Vinal's discussion of the physical chemistry of the lead-acid cell, however, suggests an attack on an explanation of these results and will be discussed below.

GENERAL PRINCIPLES

In the study of the history of a nation, the first step is to determine the general principles which govern its development. This is done by examining the various factors which influence its progress, such as its geographical position, its climate, its population, and its political institutions. The second step is to determine the specific principles which govern the development of each of these factors. This is done by examining the various causes which influence each factor, such as the influence of the environment, the influence of the population, and the influence of the political institutions. The third step is to determine the general principles which govern the development of the nation as a whole. This is done by examining the various causes which influence the nation as a whole, such as the influence of the environment, the influence of the population, and the influence of the political institutions.

(1) The first principle is that the development of a nation is determined by its geographical position.

(2) The second principle is that the development of a nation is determined by its climate.

(3) The third principle is that the development of a nation is determined by its population.

(4) The fourth principle is that the development of a nation is determined by its political institutions.

(5) The fifth principle is that the development of a nation is determined by its economic system.

(6) The sixth principle is that the development of a nation is determined by its social system.

(7) The seventh principle is that the development of a nation is determined by its cultural system.

(8) The eighth principle is that the development of a nation is determined by its religious system.

(9) The ninth principle is that the development of a nation is determined by its scientific system.

(10) The tenth principle is that the development of a nation is determined by its artistic system.

(11) The eleventh principle is that the development of a nation is determined by its literary system.

(12) The twelfth principle is that the development of a nation is determined by its musical system.

(13) The thirteenth principle is that the development of a nation is determined by its theatrical system.

G. W. Jernstedt, of the Westinghouse Electric Corporation, investigated and patented an electroplating process in which the plating current is periodically reversed. In the Westinghouse Engineer [7] he described the circuits and apparatus used, and gave a qualitative theory explaining the improved plating produced by this method. Neither this article, however, nor any of the other references to periodic-reversal, or "PR" plating (see Bibliography) suggested an explanation for the effects of pulsating charging on storage batteries.

Guided by these references and some experience with submarine storage batteries, the investigators decided to conduct an experiment in which a lead-acid battery would be repeatedly cycled, the finishing-rate current being pulsed at different frequencies. Steady current control charges were to be made for comparison. It was hoped to discover whether benefits similar to Dacos' could be obtained if the charging current were pulsed at a frequency on the order of 1 or 2 cycles per second. Varying the field of a conventional submarine main generator, perhaps by a commercial PR electroplating control, could produce such a current, while a higher frequency on the order of 50 cycles would be difficult to obtain. While the improved performance achieved by Dacos would be valuable in any battery, it would be exceptionally desirable in a submarine battery where high performance and minimum gassing are essential. Since the experimental setup could be adapted for higher frequency work, the frequency range was extended from 0.5 to 400 cycles per second.

the element and separate out, and give a qualitative study explaining the improved design embodied by this method. Within this article, however, not any of the other references is omitted, or "the" tag (see Bibliography) suggested as substitution for the words of reference.

It is to be noted that the Commission has not yet received any information from the Government of the United States regarding the results of the investigation conducted by the Department of the Interior in 1941. The Commission is of the opinion that the investigation conducted by the Department of the Interior in 1941 was not a complete one and that the results of the investigation were not reliable. The Commission is of the opinion that the investigation conducted by the Department of the Interior in 1941 was not a complete one and that the results of the investigation were not reliable. The Commission is of the opinion that the investigation conducted by the Department of the Interior in 1941 was not a complete one and that the results of the investigation were not reliable.

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CHAPTER II

PROCEDURE

The first step in a study of pulsating-current charging, the investigators decided, should be to determine the effects on cell performance rather than to study electro-chemical phenomena. Several motives prompted this decision:

(1) Unless improved performance were found to exist, there would be little incentive to study the electro-chemical reactions involved.

(2) The background of the investigators was electrical rather than chemical.

(3) Available laboratory facilities lent themselves better to measuring and controlling electrical rather than chemical variables.

It was therefore decided to study the variation with pulse repetition frequency of the following indices of cell performance:

(1) Ampere-hours per charge, and ampere-hour efficiency;

(2) Watt-hours per charge, and watt-hour efficiency;

(3) Gas generation per charge, per watt-hour, and per ampere-hour; and

(4) Duration of charge.

The general scheme was to connect several cells in series and repeatedly cycle the battery. Since variations in ambient temperature were small, temperature was left uncontrolled with the thought that its effect could be neglected. Otherwise all cycles were as nearly identical as possible except that the current during the finishing rate of each charge was pulsed at a different frequency. Average current was kept the same for each charge.

1. *Journal of the American Medical Association*, 1997; 277: 1001-1005.

Article 104: The State shall protect the environment and improve the living environment of the people.

Thus any variation in performance among the cycles should have been due only to the variation in frequency.

A program of experimental work was laid out to determine these data. It later turned out to be too ambitious for the time available, and only parts a, b, c, and d were completed. The schedule, with the approximate times of laboratory and shop work required, was:

- a. Design, construct, and test the experimental setup (20 weeks).
- b. Cycle the battery at frequencies of 0.5, 1, 3, 7.8, 20, 40, 100, and 400 cycles. Use square pulses at low frequencies, half wave rectification at higher frequencies. (4 weeks)
- c. Cycle the battery several times with steady current charging for a comparison with step b. (2 weeks)
- d. Investigate reproducibility of results of steps b and c. (1 week)
- e. If step d reveals low reproducibility, repeat steps b and c often enough to obtain an accurate mean for each frequency. A statistical analysis of the results of steps b and c will be required to determine how many additional runs at each frequency are required.
- f. Repeat these steps for different wave shapes including full wave rectification and pulsed field excitation.

The experimental setup was designed along the lines of Figure 1, which shows a simplified block diagram of the equipment. In general, the battery was discharged for a predetermined number of ampere-hours, then fully charged. The charge was considered to be completed when cell voltage ceased to rise. The gas generated in each cell during the finishing rate was collected and measured. Cell current and voltages were recorded. Electrolyte

There was no significant difference in the results of the two groups.

On the variation in frequency.

A program of experimental work was laid out to determine these data.

It is noted that the results of the two groups were not significantly different.

There was no significant difference in the results of the two groups.

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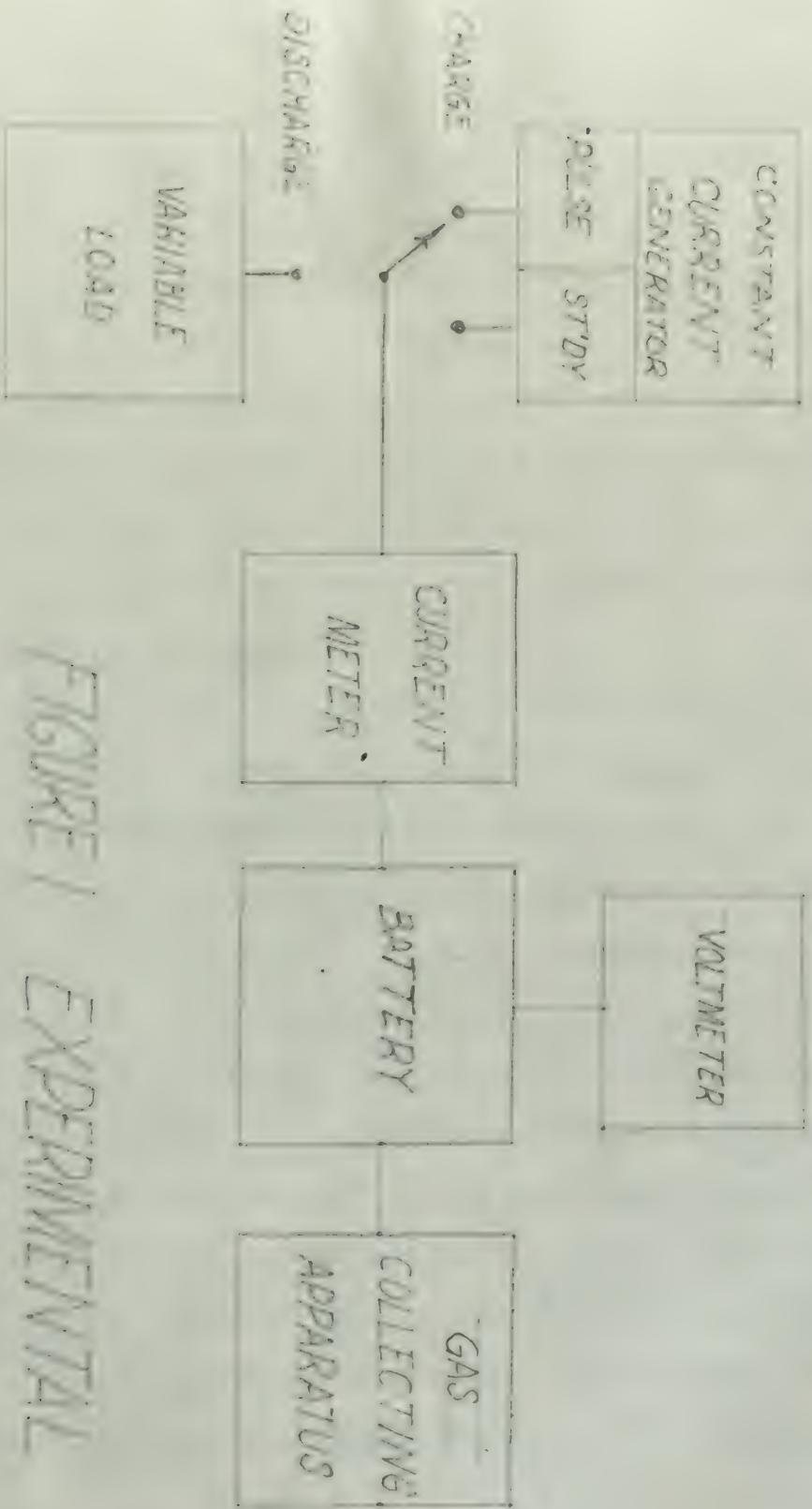


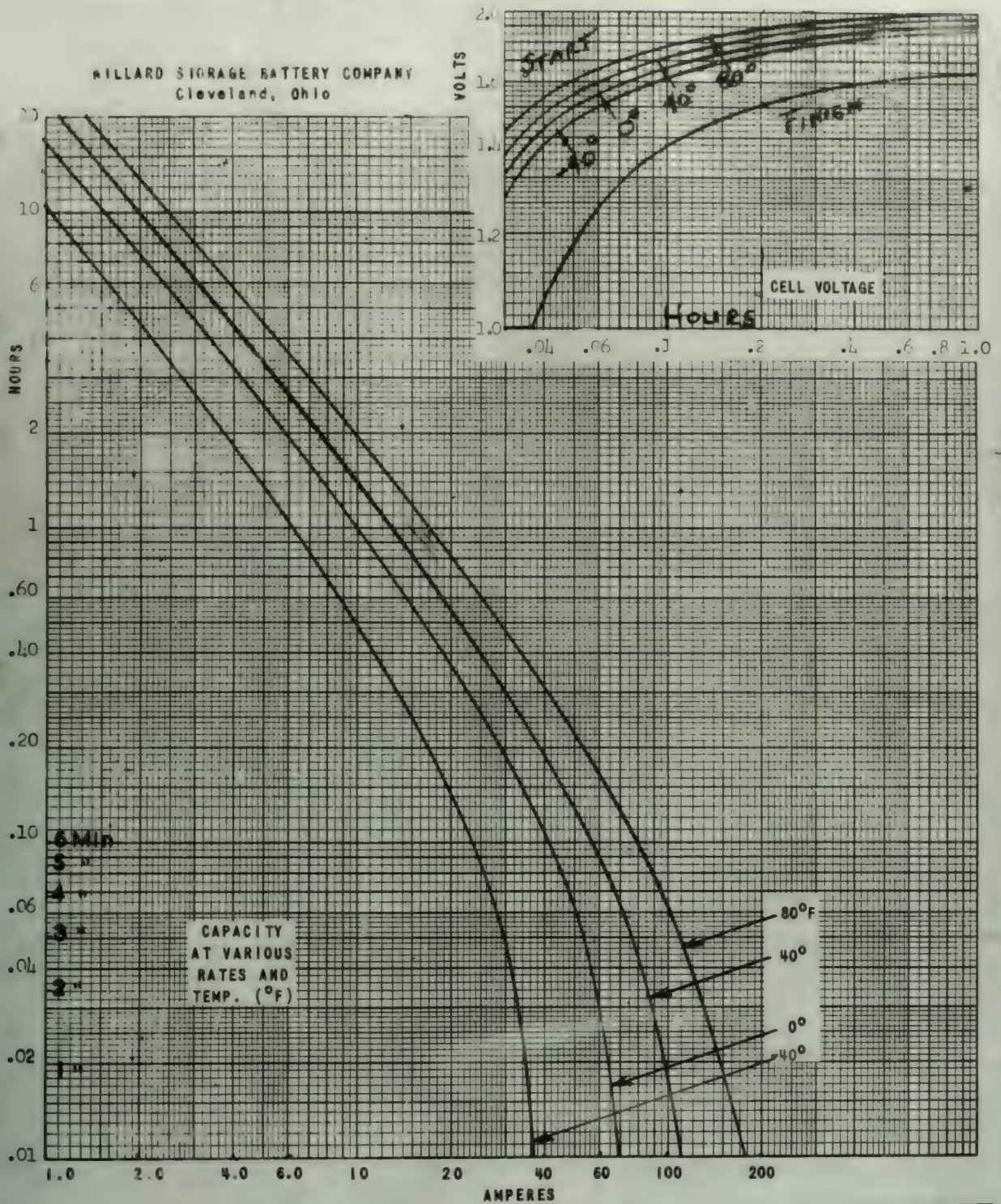
FIGURE 1 EXPERIMENTAL
SETUP

temperature was measured but not regulated.

To regulate and measure these simple data (voltage, current, gas volume, and temperature) required a more complicated arrangement than originally anticipated. Like Topsy it "just grew", until sometimes ten pieces of relatively large rotating machinery had to be run simultaneously. The details of the setup are given at length in Appendix A. As the experiment proceeded, some improvements were made, and some were noted but could not be effected. In particular, the substitution of recording instruments for indicating instruments would have simplified both the regulating and data-taking problems. This and other improvements are more fully discussed in Chapter V.

It was decided to use three Willard Type MR-24-2 cells for the experiment. This cell is a small, plastic-encased, non-spill type having a nominal capacity of 24 ampere-hours with a specific gravity of 1.280. The manufacturer's performance curves are shown in Figure 2 and the Bureau of Ships drawing in Figure 3. A small cell with a low charging current was necessary if square current pulses were to be produced by relaying. A small cell also would generate a relatively small volume of gas and minimize the problem of gas collection and metering and the hazard from hydrogen-oxygen explosions. While realizing that this cell is a far cry from the 5000 ampere-hour submarine cell in which they were primarily interested, the investigators considered that both cells would react similarly to pulsating-current charges. The reactions are the same in each cell, and the voltage, specific gravity, and plate-current density

WILLARD STORAGE BATTERY COMPANY
Cleveland, Ohio



DRY WEIGHT 2.86 POUNDS

WET WEIGHT 3.82 POUNDS

TERMINAL VOLTAGE 2.0 VOLTS

MAXIMUM DIMENSIONS

LENGTH 3 31/32 IN.

WIDTH 3 IN.

HEIGHT 5 1/2 IN.

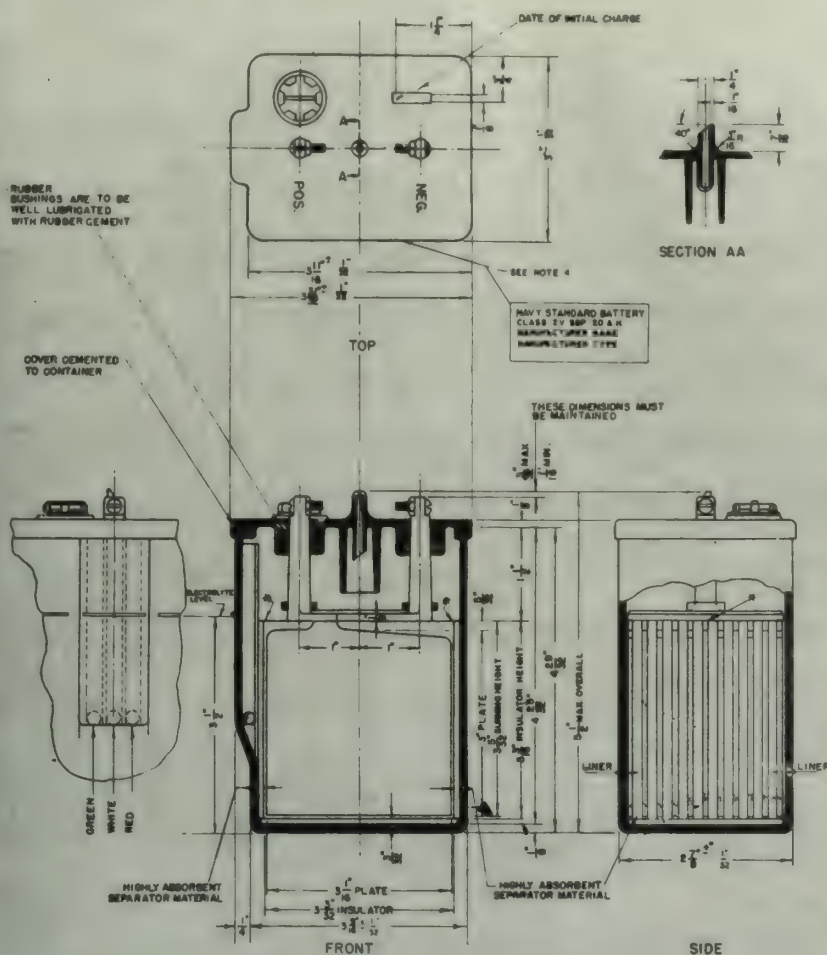
2 VOLTS

TYPE ER-24-2

DATE 5-29-50

CURVE 17

FIGURE 2 PERFORMANCE CURVES FOR
WILLARD CELL TYPE ER-24-2



- NOTES
1. BATTERY INDICATOR BALLS
GREEN RISES WHEN FULLY CHARGED
WHITE DROPS WHEN 50% DISCHARGED
RED DROPS WHEN 90% DISCHARGED
 2. CEMENT LINER IN PLACE AT POINTS INDICATED BY #
 3. THE CASE AND COVER SHALL BE MADE OF POLYSTYRENE OR OTHER APPROVED MATERIAL (NOT HARD RUBBER)
 4. LETTERS TO BE STAMPED, MOLDED OR ENGRAVED ON CASE IN AN APPROVED METHOD.

FIGURE 3
TEST CELL

DATE PLATE DATA AND NOTE 4 ADDED		10/1/61
TITLE BLOCK CHARGED FROM TO 20 AH		10/1/61 TBC
BY	REMARKS	DATE
ALTERATIONS		

PORTABLE STORAGE BATTERY
CLASS 2V-SBP-20AH

SCALE 12 INCHES = 1 FOOT

BUREAU OF SHIPS
NAVY DEPARTMENT

WASHINGTON, D.C. FEB 12/61

FOR CHIEF OF BUREAU

DESIGN OF	INDEX GROUP	FILE NO.
TRADED BY	9 S	5408L ALT. 1

are similar. Furthermore there was no available equipment for cycling a cell of very large capacity.

The cells were obtained in the charged and dry condition, with the cell openings sealed. All cells were filled with 365 milliliters of reagent grade sulfuric acid of 1.280 specific gravity. After charging for 24 hours, as recommended by the manufacturer, the cells were cycled 4 times. Discharges were at 15 amperes for 48 minutes, or 12 ampere-hours. Charges used two steps of constant current with a starting rate of 6 amperes and a finishing rate of 2.4 amperes. Current was lowered to the finishing rate when any cell reached the gassing voltage determined from the Temperature-Voltage-Gassing curve shown in Figure 4. By the fourth preliminary cycle, cell voltages at end of discharge and at end of charge were substantially constant, and it was considered that no appreciable change of cell characteristics would occur with further cycling.

To be able to fill a hydrometer barrel, it was necessary to keep the electrolyte level about one centimeter above the level line on the cell jar. The gravity of this upper layer of electrolyte changed very slowly, dropping only ten or twenty points during a one-hour discharge. Since gravity readings were not significant, the filling plugs were inserted and sealed with wax after the fourth preliminary cycle. No more gravities were taken until the completion of the experiment, when they were again read, and found to have dropped about 10 points. This small change was assumed to have negligible effect. Hydrometer readings were corrected

was obtained. Furthermore there was no noticeable change in the

cell of very large capacity.

The cells were obtained in the manner and by the method, with the

cell capacity noted. All cells were filled with 10% solution of

potassium permanganate with 1,000 cc. of 10% solution of potassium

for 10 days, as recommended by the manufacturer, the cells were tested

10 days. The capacity was at 10 amperes for 10 minutes, or 10 amperes-

more. The capacity was then tested at 10 amperes with a standard rate

of 10 amperes and a finishing rate of 10 amperes. The current was lowered

to the finishing rate when the cell reached the standard voltage before-

which was the temperature-voltage-terminating curve shown in Figure 1. The

the fourth preliminary cycle, cell voltage at end of discharge and at

end of charge were substantially constant, and it was concluded that no

appreciable change of cell characteristics would occur with further ex-

posed.

To be able to fill a hydrogen battery, it was necessary to have the

electrolyte level above the separator above the level line on the cell

jar. The quantity of this upper layer of electrolyte changed very slowly,

dropping only two or three inches during a complete discharge. When

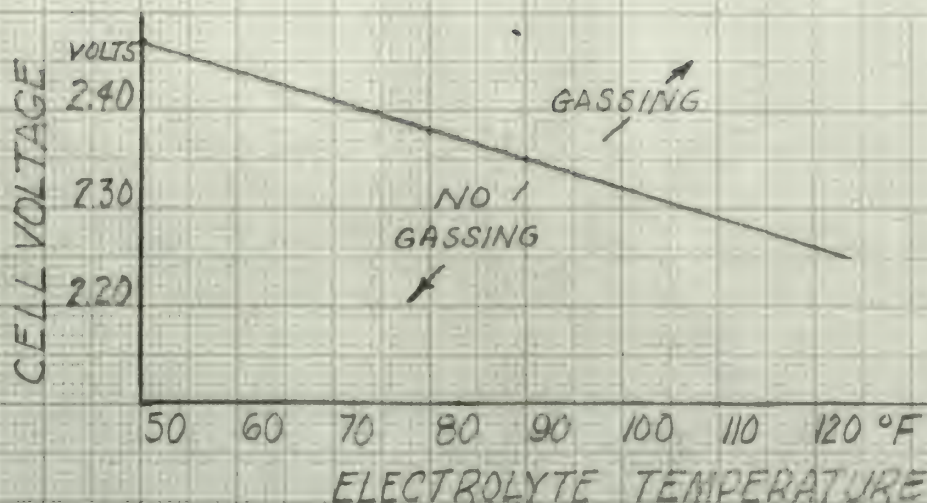
gravity reactions were not significant, the filling glass was inserted

and sealed with wax the fourth preliminary cycle. It was found

that when the cell was sealed the evolution of the hydrogen, when they were

again tested, had found to have increased about 10 percent. This small change

was assumed to have negligible effect. Hydrogen reactions were considered



TEMPERATURE-VOLTAGE-GASSING CURVE

FIGURE 4

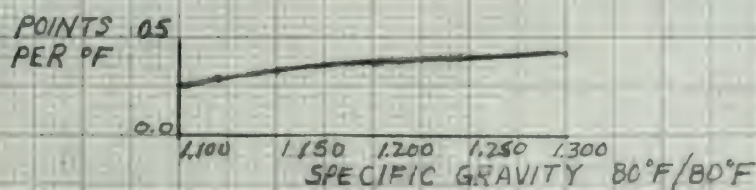
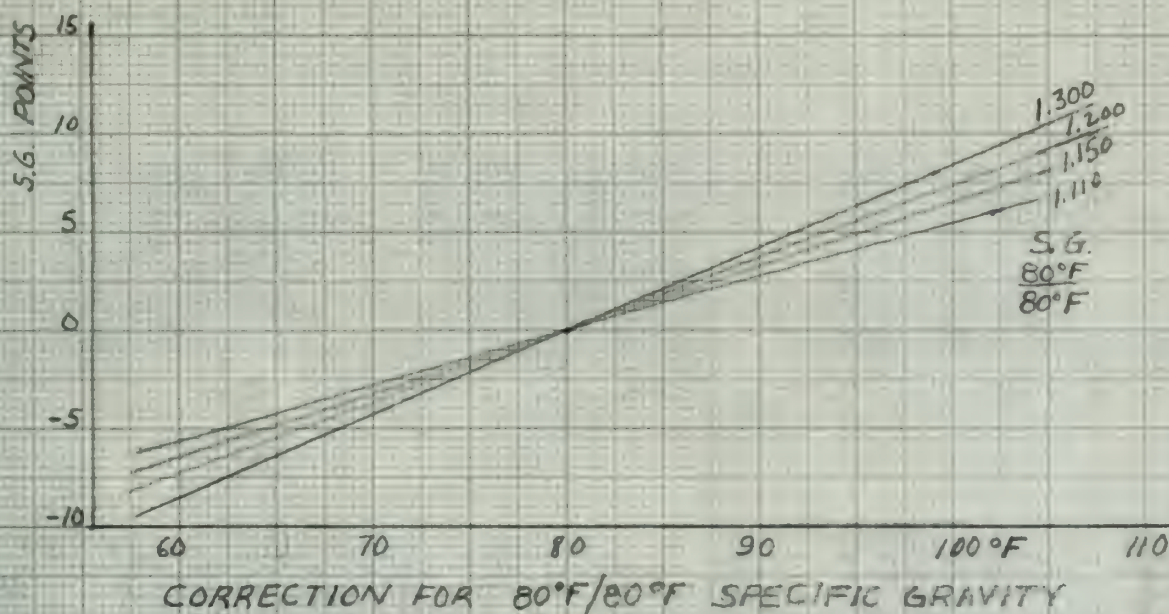
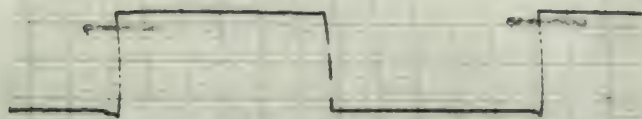
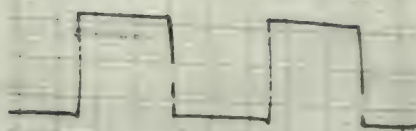


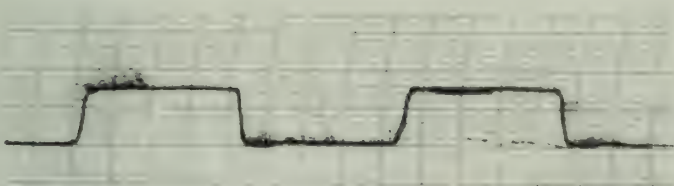
FIGURE 5 TEMPERATURE CORRECTIONS TO HYDROMETER



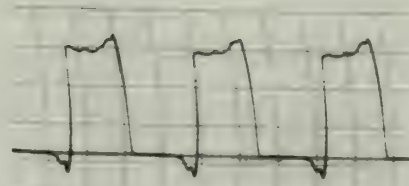
0.5 cps



1 cps



3 cps



7.8 cps



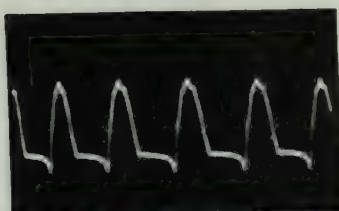
20 cps



40 cps



100 cps



400 cps



steady(with
zero current datum)

FIGURE 6. CHARGING CURRENT PULSE SHAPES

- Notes
1. Scales differ among the traces.
 2. In each case mean current is 2.4 amperes.
 3. Traces below 10 cycles per second by Brush recorder; above 10 cycles by cathode ray oscillograph.

to 80°F/80°F by the curves of Figure 5.

The current pulse shape was chosen as a square wave of equal on and off periods for frequencies below 10 cycles per second. For higher frequencies a half sine wave was used. In both cases the mean value was 2.4 amperes. Figure 5 shows the current wave shapes actually used. In some cases, on and off times were not precisely equal; in others, slot harmonics were prominent. In every case the average value was measured to be 2.4 amperes. Although the same pulse shape, either half-sine or square, would have been desirable for the entire frequency range, practical difficulties prevented it. It proved impractical to operate a relay or switch faster than about 5 cycles per second. When available alternators were run at speeds lower than that corresponding to about 15 cycles per second, it was impossible to generate sufficient voltage. Drees [3, page 17] stated that

careful trials, made with different forms of rectified alternating current, showed a very light supplementary benefit in gas evolution when one used 3rd harmonic current.

It was consequently assumed that the square wave and the half sine wave would produce similar results. The "steady" current actually had a small slot ripple, but it was believed that the ripple produced no appreciable difference from a truly constant direct current.

After the fourth preliminary cycle the test cycles were begun. Steady and pulsed runs were conducted in a random order to counteract any effect of progressive changes in the battery with cycling. The test cycles followed the same procedure as the preliminary cycles. The cells were discharged for 48 minutes at 15 amperes, then put on charge at 6

The various points which are shown in a typical case in the
 the points for the various values of α are shown in the figure. The
 a half line was not used. In fact, since the curve for $\alpha = 1$
 is shown, it is clear that the curve for $\alpha = 0$ is not
 shown, as the $\alpha = 0$ curve was not previously shown in the figure. The
 for some purposes. In every case the average value was measured in the
 1/2 degree. Although the same value shows, other values in some
 would have been suitable for the entire frequency range, provided the
 the value measured is. It is proved impossible to measure a value in
 which there is about 1/2 degree per second. When available in practice
 with the 1/2 degree limit that corresponds to about 1/2 degree per
 second, it is impossible to measure without error. [2, page

17] stated that

measured value, some of the different types of frequency at measuring
 curves show a very little change in the value
 when the value is measured.

It was previously stated that the curve for $\alpha = 1$ was
 would show other results. The figure shows that a well
 of the figure, but it was believed that the figure showed no
 difference from a half degree limit curve.

After the figure previously cited the first figure was shown.
 clearly and clearly that the curve is a curve which is measured
 any other of the various curves in the figure with regard to the
 which shows the same frequency as the frequency shown. The value
 was measured for the value of 1/2 degree, that is, as shown in 2

amperes steady current. When the gassing voltage was reached on any cell, the current was dropped to 2.4 amperes and gas collection was begun. The finishing rate current was pulsed or steady depending on whether the run was a test run or a control run. The gas was collected, individually for each cell, over water, and kept at atmospheric pressure by a leveling bulb. No attempt was made, nor was it practicable, to separate the hydrogen and oxygen formed at the negative and positive plates respectively. The gas collected was therefore a saturated mixture of hydrogen and oxygen plus the air initially in the collection apparatus. Difficulty with gas leakage was overcome by sealing the filling caps with wax.

During discharges, voltage readings were recorded at 6 minute intervals. During charge, voltage readings were taken at 12 minute intervals until the charge was almost completed. The temperature correction to voltage, 1.1×10^{-4} volts per degree F., was neglected. For the last hour or so, readings of voltage and gas level were taken at 6 minute intervals. Gas volume was corrected for temperature but not for pressure. As explained in Appendix A, the current pulsations were stopped during voltage readings at the lower frequencies and the current maintained at 2.4 amperes steady until the cell voltages were read. Although this procedure masked somewhat the change in performance due to pulsing, it was accepted as a necessary evil. Since cessation of voltage rise was the criterion for determining the end of the charge, it was essential to measure voltage accurately. A ballistic galvanometer could have been used to read the average of the pulsating voltage, but it would have added complications, especially in

engaged directly opposite. When the general voltage was raised on any cell, the current was dropped to 2.5 amperes and the cell was again engaged. The limiting rate current was raised to steady conditions as was the rate of the cell in a constant rate. The cell was collected, limiting the rate each cell, over water, and kept at constant pressure by a limiting bulb. No attempt was made, not was it possible, to separate the cells and oxygen from the negative and positive plates respectively. The gas collected was therefore a mixture of hydrogen and oxygen since the air initially in the collection apparatus. The limiting rate of the cell was determined by reading the limiting rate with the limiting rate, voltage readings were recorded as 2.5 amperes and voltage readings were taken at 15 minute intervals until the change was almost completed. The temperature variations in voltage, 1.1 to 1.2 volts per degree C., was registered. The rate of the cell, readings of voltage and rate were taken at 15 minute intervals. The voltage was registered the temperature was not the pressure. An analysis of the current collection was stopped during voltage readings at the lowest temperature and the current maintained at 2.5 amperes steady until the cell voltage was read. Although this procedure seemed somewhat the change in temperature was not noticed, it was recorded as a necessary well. Great variations of voltage were the collection for separating the gas of the change, it was essential to maintain voltage steady. A limiting rate current was not used to read the change of the limiting rate, but it would have been somewhat, especially in

maintaining accurate calibration. In any event, the data could be corrected for the amount of time when the current was steady instead of pulsating. An ordinary d'Arsonval movement voltmeter was therefore used for all charges.

Part b of the program was considered completed after runs at 0.5, 1, 3, 7.8, 20, 40, 100, and 400 cycles per second, and part c after 4 steady current control runs. As discussed in Chapter III, it was difficult to reproduce results in the control runs. To discover whether the lack of reproducibility was caused by faulty experimental techniques or was inherent in cell performance, the investigators commenced part d of the program. Five cycles were run under nearly identical conditions, except that electrolyte temperature was allowed to vary over a small range. Each cycle consisted of a discharge at 15 amperes for 10 minutes plus a charge at 2.4 amperes steady current until voltage ceased to rise. Gas was collected as before. Although even a cursory study of the results showed the desirability of more runs, lack of time forced a stop to experimental work. The analysis of results and writing of the report were then undertaken.

CHAPTER III

FINDINGS

The experiment proved several points conclusively and gave somewhat less conclusive answers to several other questions. An incidental conclusion was that the manufacturer overestimated the cell discharge capacity at the 15 ampere rate. According to the curves of Figure 2, the cells should deliver 15 amperes for 71 minutes at 80°F., for 65 minutes at 70°F., or for 60 minutes at 60°F., before cell voltage reached the minimum allowable of 1.65 volts. On one occasion, the cells reached a voltage of 1.62 by the end of a 48 minute discharge at 15 amperes. On another occasion, when the cells were discharged to the low voltage level, they delivered only 80% of rated capacity. The usual voltage at the end of 48 minutes was 1.8, dropping rapidly. Although the discharges were always terminated after 48 minutes, it was exceedingly doubtful whether the cells would have discharged for 17 more minutes without reaching 1.65 volts. A similar conclusion was reached by the Mare Island Naval Shipyard Industrial Laboratory [8] in tests of 12 similar cells. (They were of the same Navy stock number, but manufacturer not specified.) The laboratory found an average ampere-hour efficiency of 94% at the 15 ampere rate, although performance at the 5 minute and 10 hour rates was excellent.

A second conclusion was that fluctuation in cell voltage, when the battery was charged with a pulsating current, decreased as the frequency increased. Voltage ripple, defined as the ratio between voltage fluctuation and mean voltage, decreased from .124 at 0.2 cycles per second

RESULTS

The experiment proved several points conclusively and gave valuable data concerning attempts to convert other materials. An isolated example is given below. The phenomenon observed was that the cells delivered a current of 1.5 amperes at the 15 minute mark. According to the curves of Figure 2, the cells should deliver 15 amperes for 15 minutes at 60%, for 15 minutes at 70%, or for 15 minutes at 80%, before cell voltage reached the minimum value of 1.5 volts. On one occasion, the cells reached a voltage of 1.5 by the end of a 15 minute discharge at 15 amperes. On another occasion, when the cells were discharged to the low voltage level, they delivered only 10% of rated capacity. The actual voltage at the end of 15 minutes was 1.5, however rapidly. Although the discharges were always successful after 15 minutes, it was immediately evident whether the cells would have discharged for 15 minutes without reaching 1.5 volts. A similar observation was recorded by the same student level laboratory laboratory. (2) In tests of 15 minute cells. (They were of the same type as those, but somewhat less specified.) The laboratory found an average current efficiency of 90% at the 15 minute rate, although percentages of the 5 minute and 10 hour rates was excellent.

A second conclusion was that the reaction in cell voltage, when the battery was charged with a reducing current, depended on the frequency of the voltage ripple, defined as the ratio between voltage from

becoming roughly asymptotic to .025 at frequencies above 2 cycles per second. The actual values are shown in Figures 7 and 8.

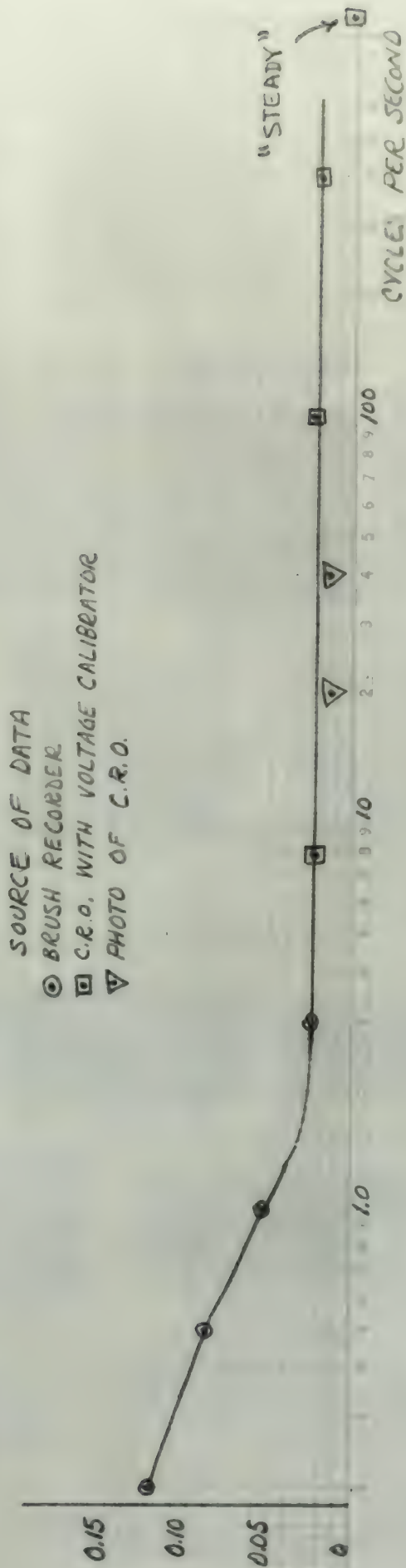
<u>Frequency</u>	<u>Ripple</u>	<u>Current Shape</u>	<u>Source of Data</u>
0.2	0.124	square	Brush recorder
0.5	0.090	do.	do.
1.0	0.053	do.	do.
3.0	0.025	do.	do.
7.8	0.024	do.	Oscilloscope with voltage calib.
20	0.013	half sine	Oscillograph photo
40	0.017	do.	do.
100	0.027	do.	Oscilloscope with voltage calib.
400	0.024	do.	do.
"Steady"	0.002	ripple	do.

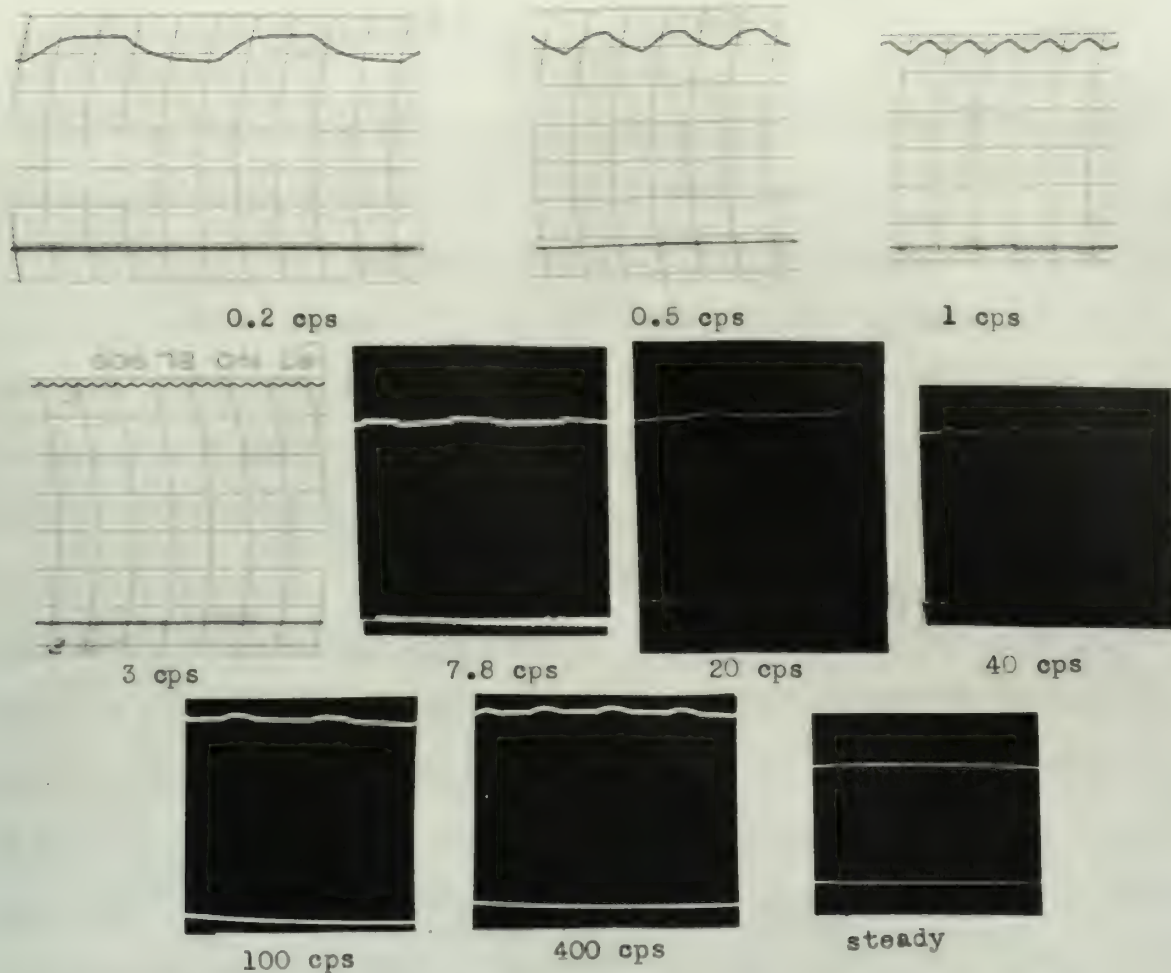
Figure 8. Voltage Ripple

Shapes of the cell voltages and voltage fluctuations are shown in Figure 9, while current shapes are shown in Figure 6 above. Ripple was substantially the same for both current shapes at frequencies above 3 cycles, although the shape of the fluctuation was different. The small, 540 cycle current ripple produced an almost negligible voltage ripple.

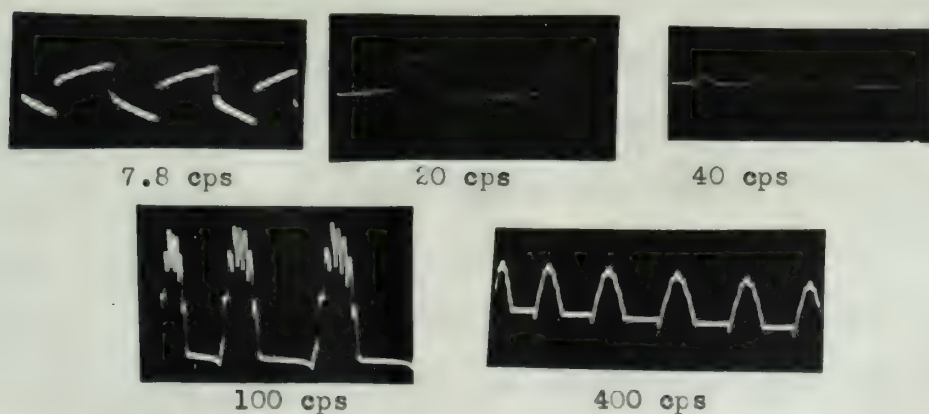
A third conclusion is that storage cell performance is not reproducible under ordinary laboratory conditions. Tests run under very similar, if not identical, conditions produced varying results. The investigators were unable to correlate indices of performance with any variable. They were forced to conclude that the indices obtained in this experiment were distributed according to an unknown frequency distribution. The experimentally observed means of these indices cannot be said to equal the true indices. It is possible, however, under certain not unreasonable assumptions, to state a range within which, at a high confidence level, each true index should lie. These confidence limits are shown on the curves

FIGURE 7
VOLTAGE RIDDLE vs. FREQUENCY





A. BATTERY VOLTAGE. Horizontal line at bottom of trace is voltage datum. Voltage 7.5 volts.



B. BATTERY VOLTAGE FLUCTUATION. Scales differ among the traces.

FIGURE 9. VOLTAGE WAVE SHAPES

of Figure 10. Since the statistical analysis is rather lengthy, it is discussed in detail in the following chapter rather than here.

A surprising fact was noted when the volume of gas per ampere-hour during the surcharges was compared with that predicted by Faraday's Law. During the surcharge (portion of charge after voltage ceases to rise) all the charge sent through the cell is transmitted by electrolysis of the water of the electrolyte. Since all the PbSO_4 has been transformed into Pb and PbO_2 , there is no other mechanism for current flow. One then expects to generate one equivalent of gas at each electrode for every faraday of electricity sent through the cell. If the hydrogen and oxygen were collected together, one would expect to collect about 715 cubic centimeters of the saturated mixture at 27°C . for every ampere-hour of charge. For all frequencies, however, the volume of gas collected was about 444 cubic centimeters per ampere-hour, 62% of the expected value. (Electrochemists would say that the current efficiency was 62%.) Figure 11 shows the values of gas per ampere-hour. The only explanation is that some of the hydrogen and oxygen have recombined into water before escaping from the electrolyte. The investigators then concluded that some of the gas produced prior to the surcharge must also recombine rather than escape. The volume of gas collected was then a function of two phenomena:

- (1) during the gassing before completion of the charge, part of the current desulfated the plates and the rest electrolyzed the water of the electrolyte,

- (2) part of the electrolytically produced hydrogen and oxygen recombined

of Figure 11. Since the electrode surface is rather large it is

measured in detail in the following manner: First the

A cylindrical test was used when the volume of the gas

during the experiment was compared with that produced by Faraday's law.

During the experiment (position of change after 10 days or more) all

the change was through the cell is transmitted by electrolysis of the

water of the electrolyte. Since all the H_2O has been removed into

It and H_2O , there is no other mechanism for current flow. One then ex-

pects to measure the equivalent of gas at each electrode for every far-

aday of electrolysis and through the cell. If the hydrogen and oxygen were

collected separately, one would expect to collect about 17.5 cubic centimeters

of the separated volume at H_2O . For every equivalent of change, for all

theoretical, however, the volume of gas collected was about 17.5 cubic centi-

meters per equivalent, 6.25 of the separated volume. (Microchemicals would

say that the current efficiency was 62.5.) Figure 11 shows the values of

gas per equivalent. The only explanation is that some of the hydrogen

and oxygen have recombined into water before escaping from the electro-

lyte. The investigators then concluded that some of the gas produced prior

to the electrolysis was also recombined before being evolved. The volume of gas

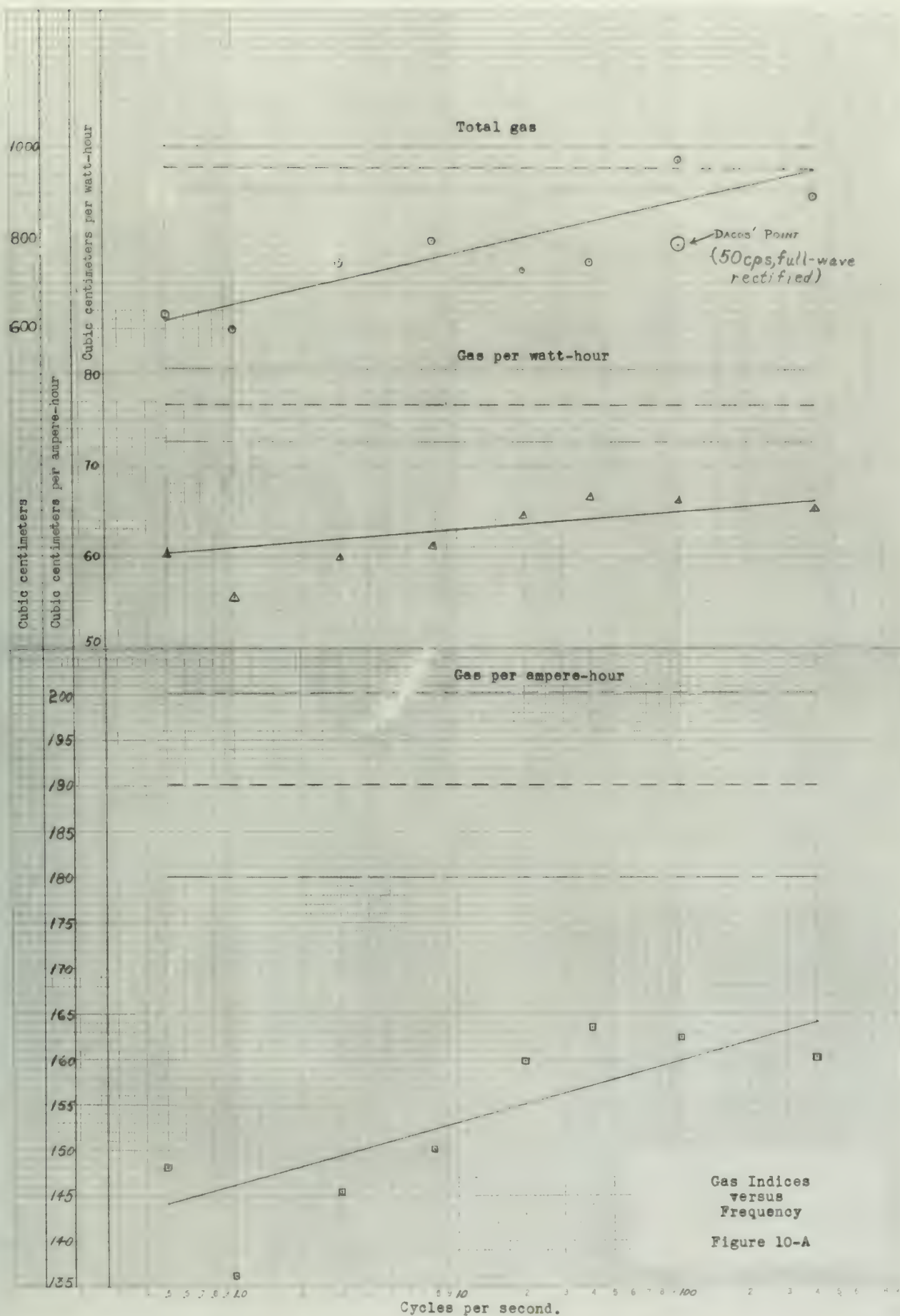
collected was then a function of the phenomenon:

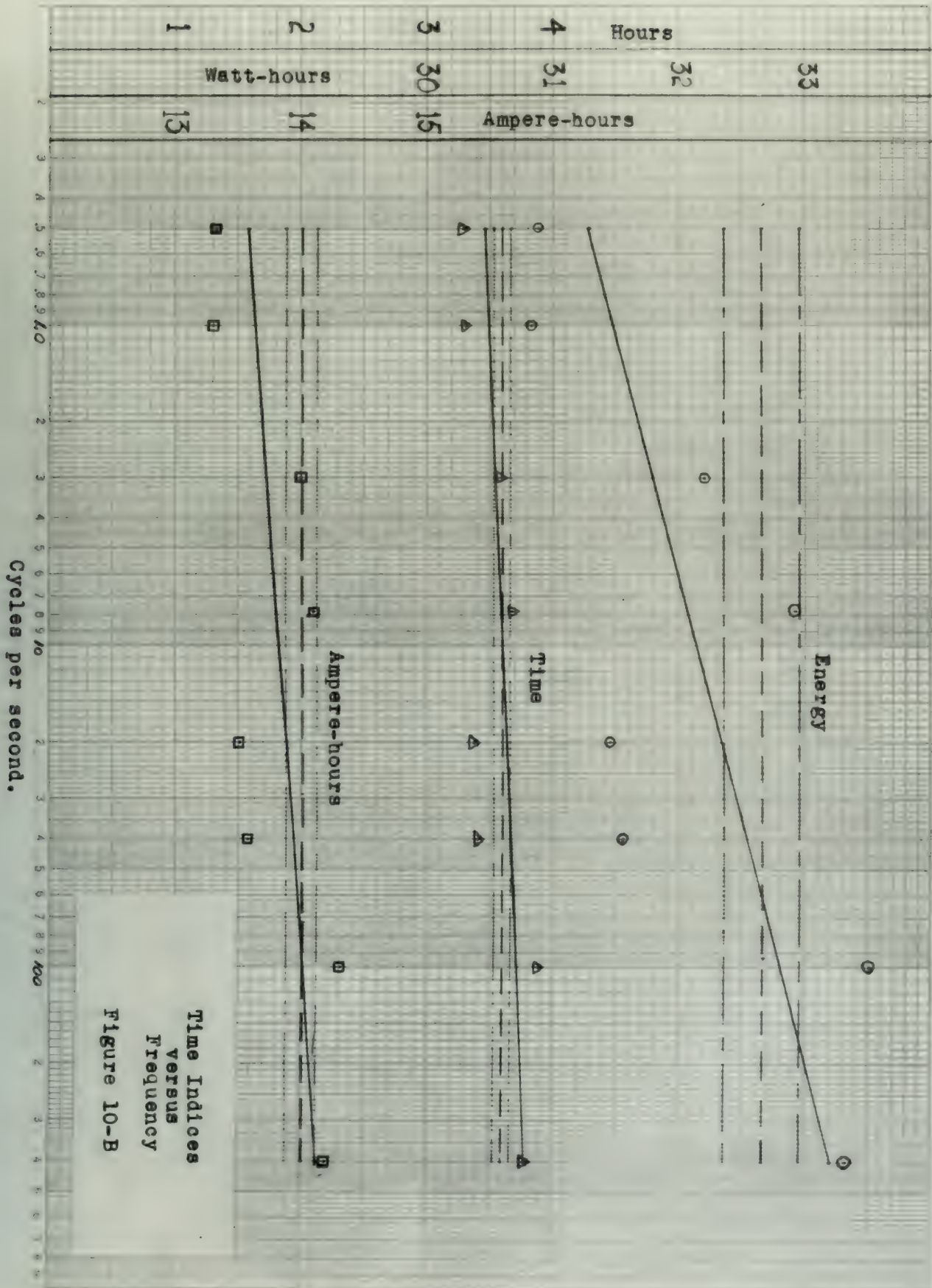
(1) During the period before completion of the change, part of the

current dissolved the plates and the rest electrolyzed the water of the

electrolyte,

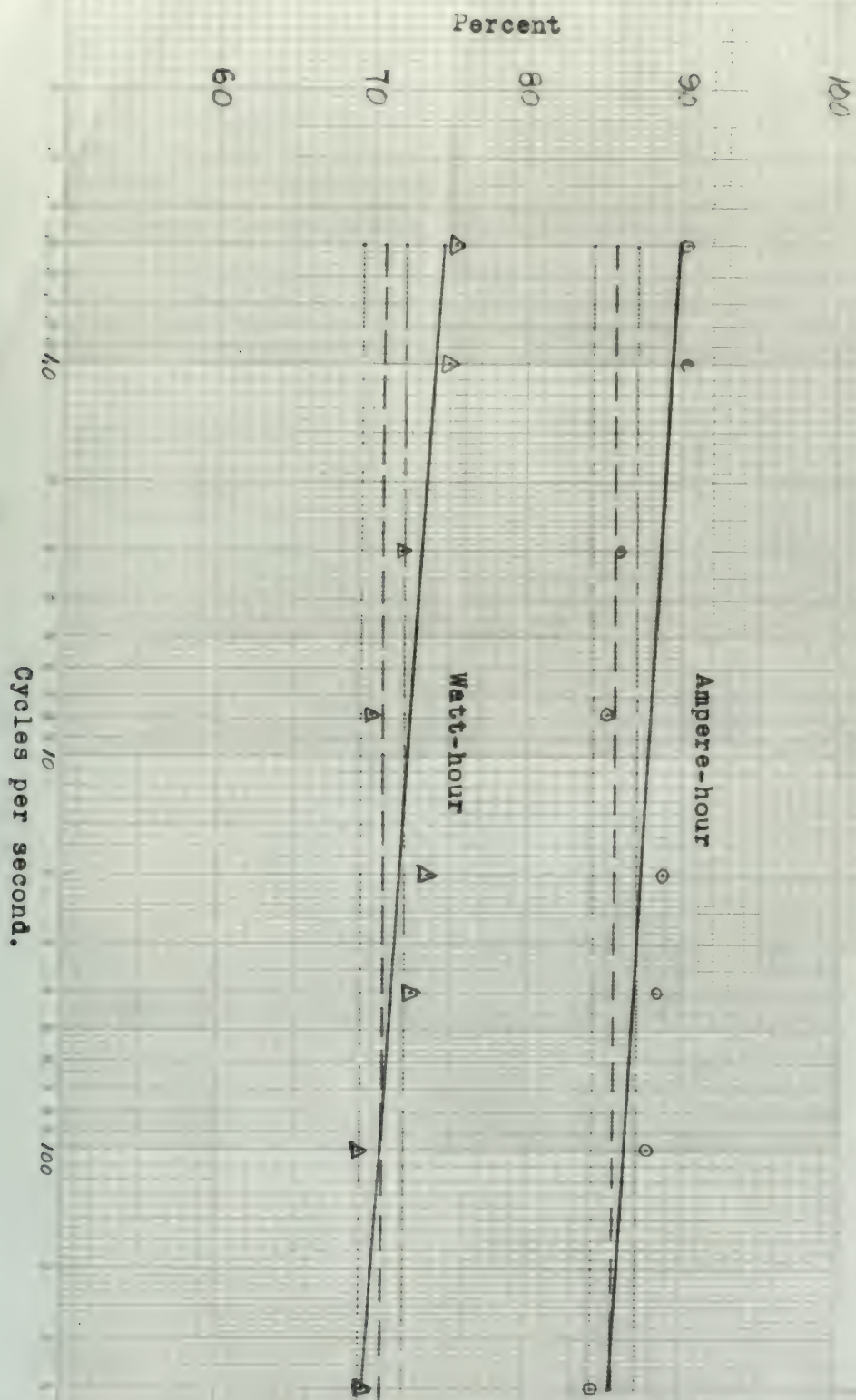
(2) Part of the electrolysis produced hydrogen and oxygen from

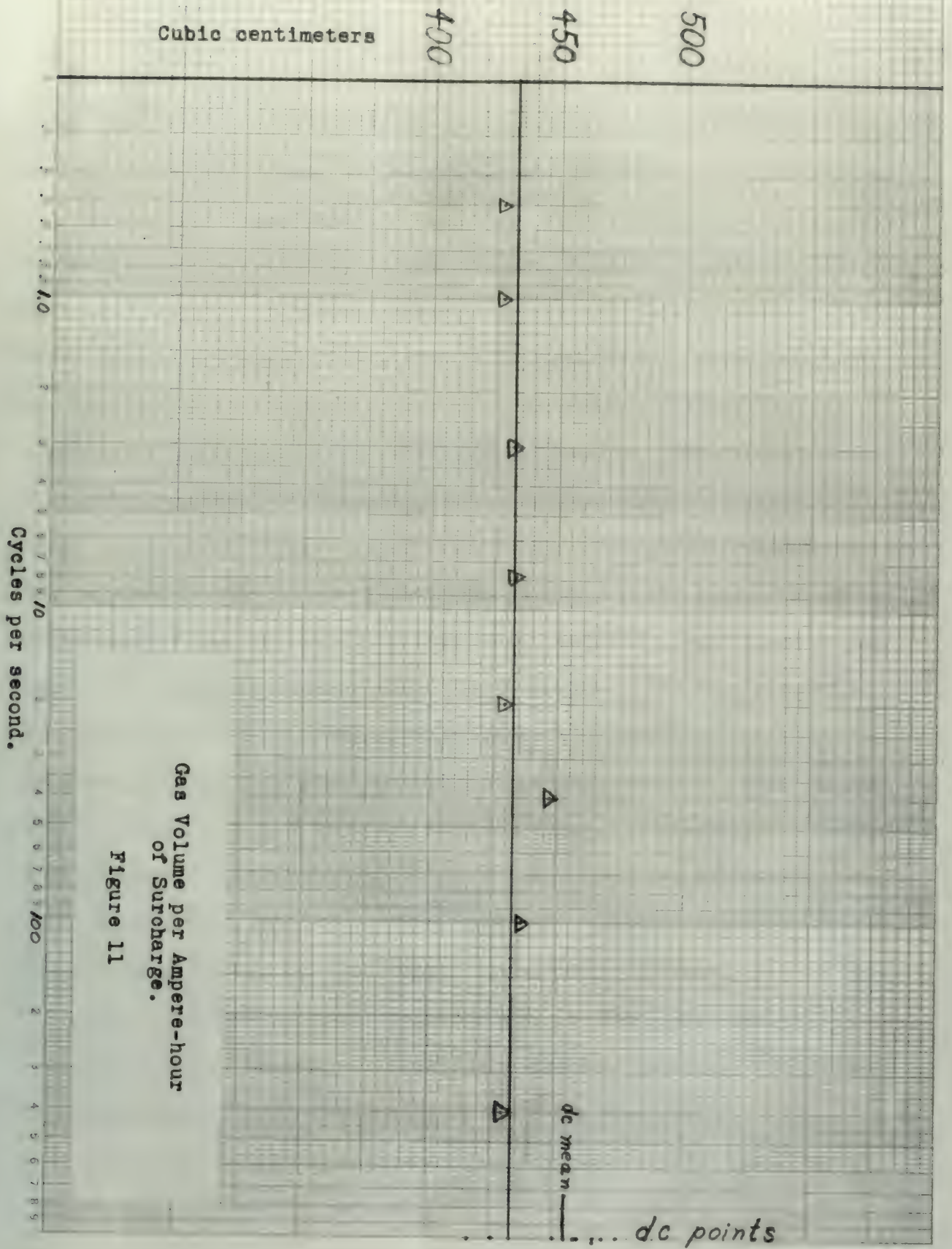




Time Indices
Versus
Frequency
Figure 10-B

Efficiencies
Versus
Frequency
Figure 10-C





bined into water and part escaped. The relative effect of these two phenomena was not determined, but it was concluded that both occurred to some extent.

The lack of reproducibility of indices of performance prevented giving an exact quantitative answer to the question, "How does battery performance vary with frequency of current pulsation?" It was obvious, however, that pulsating charges improved most indices of performance, particularly at low frequencies on the order of one cycle per second. Figure 10 shows graphically the values of the most important indices. The dashed lines in each graph represent the respective means of the steady current control runs, while the dot-dash lines on either side represent the 90% confidence limits for this mean. That is, the probability is 0.9 that the true value of the index lies between the dot-dash lines. A straight line was fitted to the points for pulsating current as the best estimate of the true situation. Confidence limits in the form of a shaded area centered on this line could have been plotted, but the computation is so tedious and the added information so little that this work was not undertaken. In general, the width of this band would be several times that of the control run confidence band. Quantitative statements being out of order, the following qualitative conclusions were reached for the various indices of performance:

Time: Possibly a slight improvement at the lower frequencies.

Ampere-hours: Possibly a slight improvement at the lower frequencies.

Watt-hours: Slight improvement at the lower frequencies.

Gas evolved: Definite improvement at the lower frequencies; little or none above 100 cycles per second.

or none above 100 cycles per second.

Low frequency: Below 100 cycles per second.

Medium frequency: 100 to 10,000 cycles per second.

High frequency: Above 10,000 cycles per second.

Results were recorded for the various indices of performance:

Quantitative measures being set at zero, the following qualitative measures were used:

1. Speed: The time taken to complete the test was recorded. In general, the faster the time taken, the better the performance.

2. Accuracy: The number of errors made was recorded. The fewer the errors, the better the performance.

3. Consistency: The standard deviation of the scores was recorded. The lower the standard deviation, the better the performance.

4. Endurance: The time taken to complete the test was recorded. The longer the time taken, the better the performance.

5. Efficiency: The ratio of the number of correct responses to the number of responses was recorded. The higher the ratio, the better the performance.

6. Reliability: The correlation coefficient between the scores on the two tests was recorded. The higher the correlation coefficient, the better the performance.

7. Validity: The correlation coefficient between the scores on the test and the scores on the criterion was recorded. The higher the correlation coefficient, the better the performance.

8. Generalization: The correlation coefficient between the scores on the test and the scores on the criterion was recorded. The higher the correlation coefficient, the better the performance.

Gas per ampere-hour and per watt-hour: Decided improvement at all frequencies tested, greatest at the lower frequencies.

Efficiencies: Slight improvement at the lower frequencies.

In summary, the greatest benefits were noted in gas evolution, with slight improvement in other indices.

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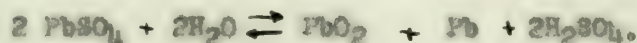
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CHAPTER IV

DISCUSSION OF RESULTS

According to the double sulfate theory, the reaction in a lead acid cell is:



During charge the reaction goes from left to right. According to Vinal [12, page 171] the cell terminal voltage is:

$$V = Ir + 1.87 + \frac{RT}{2F} \ln \left\{ \frac{[\text{Pb}^{++++}]}{[\text{Pb}^{++}]^2} \right\},$$

where

I = current

r = cell internal resistance (virtual)

R = universal gas constant

T = absolute temperature, $^{\circ}\text{Rankine}$.

F = Faraday's constant

$[\text{Pb}^{++++}]$ = concentration of tetravalent lead ions

$[\text{Pb}^{++}]$ = concentration of bivalent lead ions.

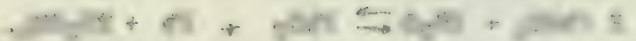
It can be shown that the concentration of the tetravalent ion increases and that of the bivalent ion decreases as the charge proceeds, the voltage thus increasing. Cell temperature tends to rise because of I^2r heating as well as because of the heat of this exothermic reaction, and cell voltage is further increased.

Electrolysis of water occurs at a voltage which varies linearly with temperature. As shown in Figure 4 above, the value is 2.38 volts at 50°F

THEORY OF THE CELL

According to the double salt theory, the reaction is as follows:

Cell 101



During operation the reaction goes from left to right. According to Nernst

[1911, page 177] the cell potential voltage is

$$V = E^\circ + \frac{RT}{nF} \ln \left\{ \frac{[\text{Ag}^+]^2}{[\text{H}^+]^2} \right\}$$

where

E° = standard

n = half reaction coefficient (valence)

R = universal gas constant

T = absolute temperature, °Kelvin

F = Faraday's constant

$[\text{Ag}^+]$ = concentration of silver ion

$[\text{H}^+]$ = concentration of hydrogen ion

It can be shown that the concentration of the hydrogen ion increases and that of the silver ion decreases as the charge increases, the cell goes unbalanced. Cell potential tends to rise because of H^+ ions, but as well as increase of the rate of this ionization reaction, and cell

voltage is further increased.

Electrolysis of water causes a change which varies linearly with temperature. As shown in Figure 2 above, the value is 0.05 volts at 25°C

and decreases as temperature increases. This voltage is usually reached when about 90% of the ampere-hours discharged have been replaced. By this time the desulfating reaction, which proceeds into the plates layer by layer, has reached almost the mid-plane of the plates. When electrolysis begins, the gas is thus formed in the midst of the active material of the plates. Until all the lead sulfate has been decomposed, part of the current goes into the charging reaction and part goes into electrolysis. When all sulfate has been decomposed, the charge is complete and all further current must cause electrolysis. The escape of the resulting hydrogen and oxygen bubbles is called gassing. These bubbles must escape through the pores of the active material. In doing so, especially at a high rate and at a high temperature, they loosen particles of active material which tend to "shed" or drop to the bottom of the cell as sediment. The capacity of the cell is proportionally reduced, and when the sediment pile grows high enough it may short circuit the plates. The mixture of hydrogen and oxygen creates an explosion hazard. As the bubbles leave the cell they entrain particles of electrolyte which lower cell capacity and corrode ventilation ducting. The energy which goes into electrolysis causes a drop in efficiency. In short, except for mixing the electrolyte, gassing performs no useful purpose and should be minimized. Reduction of gassing leads to safer, more economical operation and longer cell life.

Dacos [3, page 15] explains the reduction of gassing which he obtained as follows:

and increases as temperature increases. This volume is usually treated
 when about 500 of the water-borne dissolved parts are removed. It
 this time the dissolved portion, which amounts to the whole of the
 of water, has reached almost the stage of the liquid. When electrolysis
 the liquid, the gas is then formed in the midst of the active material of
 the liquid. Until all the liquid surface has been removed, part of the
 current goes into the sparking reaction and part goes into electrolysis.
 When all the liquid has been removed, the change is complete and all
 the active current goes into electrolysis. The escape of the remaining
 hydrogen and oxygen bubbles is called sparking. These bubbles must escape
 through the mass of the active material. In doing so, especially at a
 high rate and at a high temperature, they become carriers of active mate-
 rial which tend to 'leak' or drop to the bottom of the cell as sediment.
 The quantity of the cell is proportionally reduced, but when the sediment
 has grown thick enough it may float about the plates. The volume of
 hydrogen and oxygen bubbles as explained above. In the further stages
 the cell they contain particles of electrolyte which lower cell efficiency
 and corrode surrounding material. The energy which goes into electrolysis
 wastes a great deal of efficiency. In short, waste for doing the electrolysis,
 passing between an active surface and which is electrical. Reduction of
 energy loss of water, more economical operation and lower cell life.
 Hence [2. Part 12] explains the reduction of passing which is de-
 scribed as follows:

.... this reduction in volume of gas comes from the fact that during a charge under pulsating voltage, the voltage is, during a fraction Θ of a half-period, greater than the equivalent mean steady current, and during the rest of the half period, smaller. But, during the latter interval of time, gas stops being evolved while the voltage of decomposition [of water] is not reached, and the ions which have just reached the reacting strata of the active material enter into chemical reaction with the lead sulfate.

Since he investigated only one frequency, Dacos did not consider the effect of changing the duration of his "fraction Θ ". There is no obvious reason why a long non-gassing period should cause more reaction than several short non-gassing periods, although the higher ampere-hour efficiencies noted at low frequencies suggest that this is the case. Solution of this question would require a study using physical chemistry methods. Some of the obvious factors are geometry of the plates, porosity of the active material, temperature, specific gravity, and viscosity of the electrolyte, velocity of ions and gas bubbles, pressure, and current density. In Dacos' opinion,

The behavior of the cell depends essentially on the phenomenon of diffusion.

An investigation of this nature was out of the scope of the experiment.

Vinal's voltage equation, together with the observed variation of voltage ripple, sheds some light on the matter. A step increase of charging current from 0 to 4.5 amperes did not produce a step change in cell voltage, as seen in Figures 6 and 9. With the current level at a constant 4.5 amperes, the voltage gradually approached a maximum. The change in voltage must have been due to a change in one or more of the quantities r , T , and ionic concentrations. It is known that r is not constant and is a function at least of current and condition of charge. In fact Vinal

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It is evident that the water in the reservoir is not at the same level as the water in the lake. The water in the reservoir is at a higher level than the water in the lake. This is due to the fact that the water in the reservoir is not at the same level as the water in the lake. The water in the reservoir is at a higher level than the water in the lake. This is due to the fact that the water in the reservoir is not at the same level as the water in the lake.

[12, page 34] states that cell resistance is only a quantity which must be added to R_{external} to satisfy the equations $I = \frac{V_{\text{cell}}}{R_{\text{external}} + r}$.

Furthermore he states that the ionic concentrations cannot be measured directly. "T" could hardly be considered to vary significantly under a current pulsing as rapidly as once or twice a second. Therefore the variations in performance might be linked to variations in cell resistance or ionic concentrations. One difficulty with this hypothesis is the constancy of voltage ripple above 2 cycles. Battery performance was not constant over this range.

Although voltage ripple was not measured at frequencies below 0.2 cycles per second, it is possible to predict that it will approach a maximum on the order of 0.25 for frequencies on the order of 20 minutes per cycle for a square wave of 10 minutes at 4.8 amperes and 10 minutes at zero current. This value was computed by noting that the voltage of a fully charged cell drops from about 2.8 to about 2.2 volts within 10 minutes after a charging current of 4.8 amperes is open-circuited. If performance is best at highest voltage ripple, the optimum frequency would then be on the order of 20 to 30 minutes per cycle. (The electroplating industry uses "PR" cycles on the order of 15 seconds plate and 5 seconds deplate.) A minimum practical frequency would be set by excessive shedding that would probably be caused if peak current were maintained for a matter of minutes, even if followed by an open circuit period of equal duration. For example, the prescribed finishing rate for the Willard ER-24-2 cell is 2.4 amperes. Suppose that a "pulsating" current of 4.8 amperes for 30 minutes followed by open circuit for 30 minutes, etc., were used for the finishing rate.

from white glass, a line of ammonia. The test tube [12. and 31.]

$\frac{\partial \log T}{\partial \log \lambda}$

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Although the average current would be 2.4 amperes, excessive gassing would undoubtedly occur during the 30 minute "on" period with loss of active material through shedding. The same considerations would prohibit a pulse shape such as 24 amperes for one second followed by open circuit for 9 seconds. Although average current would be 2.4 amperes, excessive gassing and shedding would again result. Cell life could probably be reckoned in pulses rather than in months. For optimum results, three conflicting requirements evidently must be balanced:

(1) a large voltage ripple;

(2) a period long enough to produce a large ripple but not so long as to produce damaging gassing; and

(3) not too high a peak current.

An educated guess is that the best frequency would be in the vicinity of 0.01 cycles per second (period of 100 seconds).

Dacos did not observe recombination of hydrogen and oxygen during the gassing period; he collected almost exactly the volume predicted by Faraday's Laws. In the present experiment only 62% of the predicted volume was actually collected; the other 38% recombined into water before escaping from the electrolyte. The Willard non-spill cells contained highly absorbent separators which undoubtedly affected the rate of diffusion and gas escape. Dacos' cells, 42 ampere-hour Tudor type BVM 3, probably contained conventional separators which left a considerable volume of electrolyte unabsorbed. Recombination of the gas can possibly be related to this difference in construction.

Although the average current was 0.5 ampere, significant results were obtained only during the first 10 minutes of the run. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes.

(1) a large volume of

(2) a period of time in which a large volume of

to produce damaging results; and

(3) not too high a temperature.

It was found that the rate of electrolysis was proportional to the square root of the time.

0.01 cycles per second (period of 100 seconds).

These results are in agreement with the results obtained by other investigators. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes. The results showed that the rate of electrolysis was proportional to the square root of the time. For optimum results, the electrolysis should be continued for 10 minutes.

Since Dacos observed no recombination, his reduction of gassing must have been due entirely to reducing electrolysis. The present experiment demonstrated the reverse; ampere-hour efficiency was only slightly improved by pulsing; hence electrolysis was only slightly diminished. The main cause of reduction in gassing must then have been the reaction of hydrogen and oxygen to form water. This reaction would not be explosive if it proceeded continuously, since it could then liberate energy at no higher rate than it was supplied, about 6 watts. An explosion would result, however, if the gas collected for, say, 10 minutes recombined. It would liberate energy on the order of $6 \times 600 = 3600$ watt-seconds. If it were a chain reaction occurring in 0.01 seconds, the rate of energy release would be $3600 \div 0.01 = 360,000$ watts or 360 kilowatts.

It is not surprising that recombination occurs; one type of primary cell utilizes the same reaction ($\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$) to prevent polarization of the cathode. Vinal [11, page 216 ff.] discusses the reaction at length and points out that the actual reaction is not so simple as shown above, but actually involves several intermediate reactions.

As the experiment proceeded it became evident that statistical methods would be necessary to arrive at valid conclusions from the observed data. A comparison of the first four steady current control runs (step c of the experimental program) showed a disappointing lack of reproducibility of results. Two of these four runs were under suspicion, however. In run number 6, the cathetometer telescope was inadvertently moved during the gassing period and the height of gas in the collecting bottles was there-

1. The first step in the process of determining the amount of water to be released is to determine the amount of water that is available for release. This is done by measuring the flow of water in the river at a point upstream of the dam. The flow is measured in cubic feet per second (cfs). The amount of water that is available for release is then determined by subtracting the amount of water that is used for irrigation from the total flow. The amount of water that is used for irrigation is determined by measuring the flow of water in the river at a point downstream of the dam. The amount of water that is available for release is then determined by subtracting the amount of water that is used for irrigation from the total flow. The amount of water that is available for release is then determined by subtracting the amount of water that is used for irrigation from the total flow.

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fore not accurately measurable. An estimate was made, and the gas evolution computed subject to later acceptance. There was no reason to suspect the duration of charge, ampere-hours, watt-hours, or efficiencies, since the variables involved in these quantities were accurately measured.

Run number 12 was also suspected because the cell voltages on discharge dropped below the low voltage level for that rate. The charging portion of the cycle was completed, nevertheless, and the indices of performance computed. As anticipated, some of the indices differed considerably from those obtained previously.

At this point the investigators considered the advisability of neglecting the dubious results computed in cycles 6 and 12. Since their omission would tend to accentuate the difference between pulsating and steady current performance, the investigators approached the decision with conflicting emotions. On the one hand, there was excellent reason to believe the data to be extraneous. On the other hand, neglecting them would open the investigators to the charge of shutting their eyes to those data which did not confirm their theory. They consequently deferred a decision until a third series of cycles could be run. Unfortunately time did not permit the running of a number of cycles identical to the previous control runs. Instead they conducted 5 similar cycles in which the batteries were discharged at the same rate as before but for a shorter time, 10 minutes instead of 48 minutes. The cells were then charged with a constant, steady current of 2.4 amperes. Data were collected in the same way as before. The means and standard deviations of the various indices of performance were computed.

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At this point the investigators examined the stylability of melody and the rhythmic quality of the lyrics. The results of the analysis are shown in Table 1. The results show that the melody is highly stylable and the lyrics are highly rhythmic. This suggests that the song is well suited for a musical performance.

...but let

The assumption seemed reasonable that the second set of control runs should show the same spread of data as the first set. For example, if ampere-hour efficiencies for the second run fell between 80% and 85%, they could be expected to fall within a similar range for the first run. In statistical terminology, it was assumed that the first set of runs comprised a sample from a population having a certain mean and standard deviation. The second set of runs were assumed to comprise a sample of a second population having a different mean but the same standard deviation.

Hoel [6] and Wilks [13], in their discussions of small sample techniques, describe a test for the compatibility of variances. It involves the "F" distribution tabulated by Fisher and Yates [4, table V]. Briefly, the investigators followed this procedure:

1. The first two steady current control runs, numbers 1 and 7, were assumed to be random samples from normally distributed population A having mean μ_A and standard deviation σ_A ; the second set of five, from normally distributed population B having mean μ_B and standard deviation σ_B .

2. It was assumed that $\mu_A \neq \mu_B$, but $\sigma_A = \sigma_B$.

3. An hypothesis H was then made that the dubious runs, numbers 6 and 12, also came from population A.

4. Under hypothesis H, the standard deviation S_A of the first four control runs should be compatible with the standard deviation S_B of the second five runs. This hypothesis was tested by forming the ratio

$$F = \frac{n_A S_A^2 (n_B - 1)}{n_B S_B^2 (n_A - 1)}, \quad \text{where } n = \text{the number of observations (runs) comprising the sample.}$$

The F distribution yields the probability that F

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and it is almost a wallpaper of business when you get to the bottom of it.

and resulting from a different need for the same chemical substance.

2017-2018 Annual Report

Abstract. *Environ. Health Perspect.* 101:103-108 (1993). The authors have examined the relationship of various factors to the occurrence of cancer in the United States. The results of the study are presented in the form of a table. The table shows the relative risk of cancer for various factors, including age, sex, race, and occupation. The authors conclude that the relationship between these factors and cancer is complex and requires further research.

See the instructions for the use of the software.

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1. *What is the purpose of this study?*

Journal of the American Statistical Association, 1990, Vol. 85, No. 413, pp. 1039-1047.

with 50 g of individual broilers at the beginning of brooding were higher.

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7. That the probability and ability of

will exceed any given number. Entry into Fisher's tables shows that, under hypothesis H, the probability that $F \geq 4.75$ is only 0.08. Noting that $F \geq 4.75$ for the indices t , v , v/η_f and v/η_w , one rejected the hypothesis H in their cases, but accepted it for Q_c , η_c , η_a and η_w . In other words, the volume data for runs 6 and 12 was rejected because of experimental error.

5. Volume data for runs 6 and 12 were rejected, and new standard deviations S_A' computed for V , V/η_f , and V/η_w . This new value S_A' was found to be compatible with S_p .

6. Even when times for runs 6 and 12 were neglected, the standard deviations of time proved incompatible. Since the curve of duration vs. frequency showed no significant variations, no further statistical analysis of this variable was made.

These computations are tabulated in Figure 12. The mean steady DC values plotted in Figure 10 represent, for time, ampere-hours, and efficiencies, the results of all four control runs. For volume evolved, volume per ampere-hour, and volume per watt-hour they represent the mean only of runs 1 and 7.

The confidence limits for the means were computed by Student's distribution as described in Wilks [13] and Hoel [6.] An unbiased estimate of standard deviation was based on compatible data from the two sets of control runs.

A belated review of Dacos' conclusions showed that lack of reproducibility might have been inferred from his statement that, [3, page 17]

In this test, taken at random from among very numerous observations there is a benefit of 25% in favor of piloting current. Recall that the mean of all the tests was 18%.

The first part of the paper is devoted to the study of the asymptotic behavior of the sequence of functions $f_n(x)$ defined by the recurrence relation $f_{n+1}(x) = \frac{1}{2} (f_n(x) + f_n(x/2))$ for $n \geq 1$ and $f_1(x) = x$. It is shown that $f_n(x)$ converges to a function $f(x)$ which is continuous and satisfies the functional equation $f(x) = \frac{1}{2} (f(x) + f(x/2))$. The second part of the paper is devoted to the study of the asymptotic behavior of the sequence of functions $g_n(x)$ defined by the recurrence relation $g_{n+1}(x) = \frac{1}{2} (g_n(x) + g_n(x/2))$ for $n \geq 1$ and $g_1(x) = x^2$. It is shown that $g_n(x)$ converges to a function $g(x)$ which is continuous and satisfies the functional equation $g(x) = \frac{1}{2} (g(x) + g(x/2))$.

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	S_A^2	S_B^2	F	$F_{92\%}$	SIGNIFICANT AT 92% CONFIDENCE LEVEL?	$S_A'^2$	F'	$F'_{92\%}$	SIGNIFICANT AT 92%?
BASED ON									
RUNS	A1, A6, A7, A12	B1 + B5				A1, A7			
n	4	5				2			
DEGREES OF FREEDOM	3	4				1			
INDEX:									
t	0.0132	0.0027	5.21	4.75	YES	0.0250	14.8	5.8	YES
Q_c	0.0384	0.008704	4.70		NO	—			
W_c	0.2330	0.05986	4.15		NO	—			
V	9.705	1.792	5.77		YES	2031	1.81	5.8	NO
V/Q_c	449.5	94.28	5.09		YES	76.2	0.77	123	NO
V/W_c	68.52	15.33	4.77	Y	YES	11.16	0.72	123	NO
η_Q	1.395	4.469	3.00	5.8	NO	—			
η_W	1.399	3.316	2.22	5.8	NO	—			

Dacos made no explicit mention, however, of difficulty with spread of results, nor did Vinal's chapter on Tests [12, Chapter IX] warn of this pitfall. Only after considerable grief did the investigators discover what Dacos had implied: that a few large samples would have been preferable to a number of small samples.

These data are sufficient to show, however, that the
 value of the function $f(x)$ is not zero at this
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CHAPTER V

SUGGESTIONS FOR FURTHER INVESTIGATIONS

This experiment raised more questions in the minds of the investigators than it answered. In the first place, it failed to prove precisely which pulsing frequency and shape produce optimum performance; this basic question remains to be solved. It did reveal, however, other questions which must be answered before the solution can be found. It also emphasized related problems and suggested techniques which can simplify and improve experiments with storage batteries. Some of these points are discussed briefly in three categories:

A. Questions whose answers are essential to a solution of the basic question.

B. Questions allied to the basic question.

C. Experimental techniques.

By the "basic question" is meant, "How does battery performance vary with frequency and shape of current pulses?" The discussions below merely highlight the points raised; they are presented as raw observations to be evaluated, ignored, or disproved by subsequent investigators.

A

Questions whose answers are essential to the solution of the basic question.

1. Is storage cell performance truly reproducible experimentally? That is, can all the variables be controlled and/or measured so that identical results can be produced by maintaining identical conditions? What variables are most important?

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discussed briefly in three categories:

about 100 to 150 miles a day. The distance was covered with a speed of 100 to 150 miles a day.

II. Questions allied to the basic question.

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By the "false question" is meant, "The time before mentioned was all the time during which the witness was present at the scene of the crime." The illustration below is given to show the effect of the "false question" in the case of a witness who was present at the scene of the crime.

Grasslands where animals are conserved in the wild are the focus of the study.

1. It is hereby acknowledged that the undersigned is the owner of the above described property and that the same is being offered for sale by public auction.

178 That is, all the countries he mentioned and he pointed to that

Abstracts should be prepared by members of the editorial board.

What variables are most important?

2. If not, is cell performance a chance variable? If it is a chance variable, is it normally distributed, or does it follow some other distribution? How many times must a given run be repeated to determine the true mean value of a particular index of performance? If the ampere-hour efficiency is determined, say 10 times, can we confidently say that the mean of this ten-fold sample equals the population mean?

3. What wave shape produces optimum performances? Is it a square wave, half sine wave, full-rectified sine wave, or pulsed field wave? What is the optimum duty cycle? (ratio of current-on time to current-off time).

4. Would periodic reversal of charging current improve performance as it has improved electroplating quality?

5. What is the optimum pulse frequency for any given cell?

6. Does pulsing produce beneficial results on cells of all sizes and constructions?

B

Questions allied to the basic question.

1. Does pulsed current produce less electrolysis, or does it merely cause more of the electrolytically generated hydrogen and oxygen to recombine? If the first answer is "yes", ampere-hour efficiencies should be increased. If the second answer is "yes", the volume of escaping gas should be less, while ampere-hour efficiencies would remain unchanged.

2. Can indices of performance be related analytically to pulse shape and frequency, possibly by transient analysis?

1. It may be well to mention a point which is often overlooked. In the case of a single variable, as is usually indicated, we have to follow some rule in determining the best time when a given task is required to be done. The time when a given task is required to be done is determined by the efficiency of the worker, and it is found, as we have already seen, that the mean of this distribution is equal to the population mean.

2. But we have to consider another point, which is also often overlooked. What is the optimum duty cycle? (Ratio of on-time to off-time). (on-time).

3. While certain results of a single variable are known, it has improved electroplating quality?

4. That is the optimum ratio between the on-time and off-time.

5. How much more material is used in the case of all

times and conditions?



Questions allied to the basic question.

1. How much material is used in the case of all times and conditions?

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3. How much more material is used in the case of all times and conditions?

4. How much more material is used in the case of all times and conditions?

5. How much more material is used in the case of all times and conditions?

6. Can indices of performance be related quantitatively to time and cost?

3. If a test cell consisting of two plates, widely separated, were charged with pulsating current and the gas from the respective plates collected separately, would performance be improved?

4. Is "shedding" of active material a function of total gas formed or only of that fraction of the gas which escapes without recombining into water?

C

Experimental techniques.

1. The use of recording instruments, either in addition to or in lieu of indicating instruments, would simplify the problems of recording data, computing results, and regulating charging current. Esterline Angus recording milliammeters could be connected to measure cell voltages and charging current. Several advantages would be:

a. Continuous data record, rather than only a periodic record. This feature would allow closer determination of the time of end of charge than would the constancy of two successive readings separated by a time interval.

b. Elimination of time-consuming reading and logging.

c. Quick computation of time-average values, such as voltages, by planimeter, and quick and accurate determination of time rates.

d. Elimination of need for extremely accurate current regulation. In the present experiment, current had to be maintained exactly constant to permit accurate determination of ampere-hours as the product of current and time. If ampere-hours could be determined by planimeter,

2. It is also well known that the glass, which is used,

was changed into a liquid state and the two the respective state

collected separately, which is necessary to improve

3. The "character" of the material is determined by the type

of its use in the production of the two which are not necessarily in-

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slight variations in current would be permissible.

e. The higher inertia of recording instruments would give them a better integrating characteristic than indicating instruments. The ballistic galvanometer for current metering might prove unnecessary.

2. Since individual cell performances for a given cycle were averaged, time could be saved by metering battery voltage and gas rather than individual cell values. In this way a large number of cells could be used, rather than only three, and more reproducible mean data might result.

3. The development of a recording device for volume of evolved gas would facilitate data collection.

4. Most important of all, a number of observations should be made at each frequency at which performance is to be determined accurately. Student's distribution shows that the confidence limits for a population parameter are narrowed as the number of observations is increased. Qualitatively this means that the average of the observed data for a number of runs approaches the true value as the number of runs approaches infinity. Note that the number of observations can be increased either by repeating runs or by connecting more cells in series.

5. Bearing in mind the perversity of storage batteries in failing to behave reproducibly, the investigator should heed Hoel's warning: [6, page 215]

Too many experimenters do not seem to appreciate the obvious injunction that the time to design [statistically] an experiment is before the experiment is begun.

A study of Hoel's Chapter XII on "Statistical Design in Experiments" should assist in planning a valid and efficient experiment.

slight variations in current would be possible.

4. The slight increase in current during the first part

of the first half-cycle is due to the fact that the

initial polarization of the system is not yet at equilibrium.

5. When the initial cell polarization is at a given value, the

rate of change of current is proportional to the square of the

initial cell voltage. In this way a large number of cells could be used,

rather than only three, and more reproducible data could be obtained.

6. The development of a potential across the system of electrodes

would facilitate data collection.

7. Most important of all, a number of observations should be made at

each frequency at which comparison is to be obtained experimentally. The

best's explanation shows that the equilibrium time for a population group

under the influence of the number of observations is increased. Qualitative

of this means that the average of the observed data for a number of runs

approaches the true value as the number of runs approaches infinity. Note

that the number of observations can be increased without increasing time

or by connecting more cells in series.

8. Testing in this the possibility of simple methods in relation to

these experiments, the investigation should show that the results [6, page 123]

The many experiments in this work are similar to the others

in that the time to reach [statistical] equilibrium is very

great in the case of the experiment in question.

A study of the literature on "Statistical Methods in Psychology" shows

that in general a value of statistical significance

CHAPTER VI

CONCLUSION

The experiment, while it failed to produce the quantitative results hoped for, demonstrated qualitatively that battery performance is improved by charging with pulsating current. For the Willard EE-24-2 cell a frequency on the order of 0.5 to 1 cycle per second produced best results within the frequency range covered. Further investigation, utilizing the tools of statistics, is necessary to determine the reason for this improvement and to determine optimum pulse shape and frequency for this and other cells. There is reason to believe that low frequencies are superior to high frequencies. The investigators consider their time and efforts justified since their results not only supplement the meager knowledge about pulse-charging but also point the way for future study.

Page 100

As a result of the above, the following are the main findings of the study:

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APPENDIX A

EXPERIMENTAL SETUP

The experimental setup was designed to (1) permit close control of charge and discharge currents, and to provide a choice of currents for charging; (2) provide for metering or measuring charge and discharge currents, time of charge and discharge, and individual cell voltages, temperatures, and gas evolved; (3) provide protection against accidental "reverse current" discharge of the cells; and (4) provide a stable power supply, arranged for a minimum of interruptions or disturbances to the primary power source. A brief explanation of each of these provisions will indicate the methods and principles involved and will provide a clear picture of the overall setup. In the interests of completeness, a block diagram with descriptions, and an overall circuit diagram are included.

1. Current control.

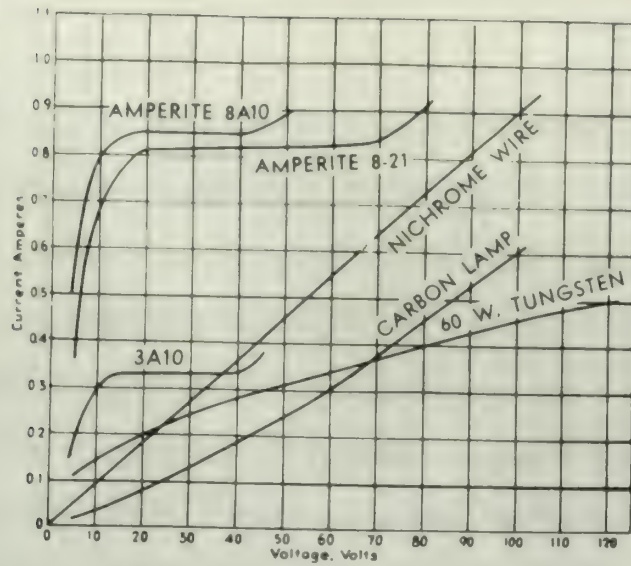
Since ampere-hour meters were unavailable, constancy of current, on both charge and discharge, was essential to the outcome of the experiment. Regulation of charging current was accomplished by the use of automatic, thermal type, variable resistance, "constant current" ballast tubes, Amperite type A-10. Characteristics of these tubes are shown in Figure 13. These tubes are designed to hold current constant to $\pm 2\%$. Supplementary rheostats were provided for very fine control, permitting excellent overall maintenance of constant current.

On discharge, the voltage of the battery alone was below the minimum operating voltage of the Amperite ballast tubes, so that discharge

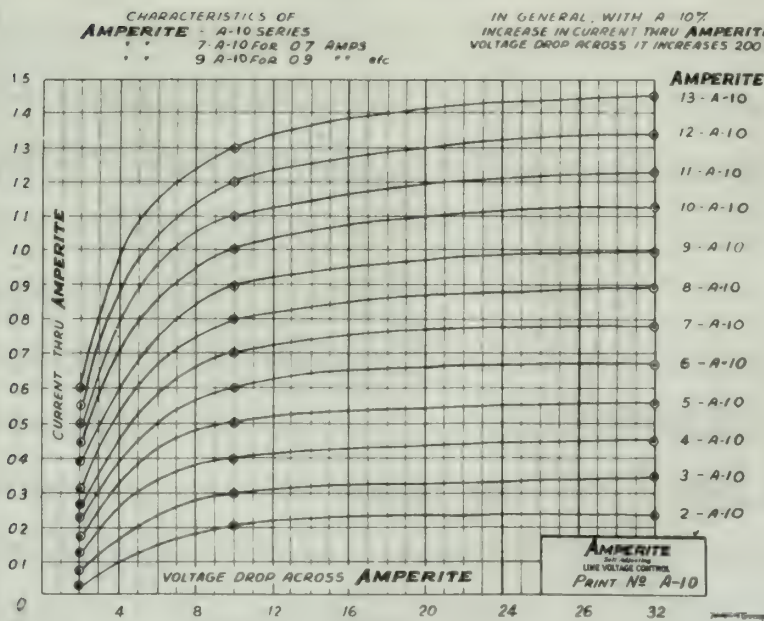
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These two lines are the only ones that are not in the original manuscript.



A. Comparison of Amperite and other resistors



B. Characteristics of A-10 series

FIGURE 13. VOLT-AMPERE CHARACTERISTICS OF AMPERITE BALLAST TUBES

current was necessarily controlled by rheostats only. Adequate control of discharge current was realized, but the rheostats required constant manipulation by the operator in order to maintain constant current.

Constant current requirements for charging included (a) a starting rate source of 6 amperes steady direct current, and for the finishing rate, (b) 2.4 amperes steady direct current, or (c) 2.4 amperes (average) pulsating direct current of square waveshape, at 4.8 amperes peak value, at frequencies from 0.5 to 8 cps, obtained from a motor driven, cam operated timer switch, or (d) 2.4 amperes pulsating direct current obtained through a half wave rectifier bank from an alternator, at frequencies from 20 to 400 cps. Of this last item, it may be said that waveshape was beyond control, since the investigators were obliged to use whatever sundry alternators that were available for this wide range of frequencies, but in any case, current was maintained at the proper average value.

2. Mensuration

The problem of metering appeared to be quite difficult at first, especially at pulsing rates below about 40 cps, where ordinary d'Arsonval movements tended to follow the current excursions rather closely, so rendering them useless for "average current" indications. In the case of current metering, when the motor driven timer switch was used, it was also necessary to consider that, although the "on" current value might be precisely 4.8 amperes, the "on" and "off" times very probably were not exactly equal*, so that the average current could not be assumed to be precise-

*This assertion was later borne out by a graphical recording of waveshape on a "Brush" recorder.

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Sentence written directly on the subject may improve readability.

Assignment to the subject is subject to the approval of the committee.

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SECRET

Appendix 2.1 is a reference guide to the data fields in the (agave) database.

Under a new building, age 8 of 2.0 new retirement is also seen

Several policies are suggested in the report, and the authors conclude that the most effective policy is to increase the minimum wage.

...the most important thing is to have a good understanding of the market and the competition.

Size of your 51 and 52 feet and 70 and 80 of 10 feet alignment to

Don't let your employees' cell phone habits become a distraction.

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only one of these two values is used to calculate the other.

— About the same relative rate would "hold" for the other 100 percent of the population.

analysts of all kinds of the three foreign systems all had as "some of

on a "Bureau" recorder.

ly 2.4 amperes. Thus, a meter which would average, or integrate, was required, and a long period, ballistic galvanometer, connected to a very low resistance shunt, provided the solution. The low resistance shunt caused the instrument to be highly overdamped, thus adding to its integrating ability. An instant acting relay arrangement was provided, whereby the galvanometer and its associated shunt could be switched into either the battery charging circuit, or into a constant current reference circuit, maintained accurately at 2.40 amperes, for purposes of zero-setting and comparison.

When charging with steady direct current, or with rectified alternating current at frequencies of 40 cps and higher, ordinary d'Arsonval type ammeters were used, and provided satisfactory current indications. It is noteworthy that the precision of every electrical meter reading which might directly influence the quantitative experimental results was enhanced by the use of magnifying glasses placed over the meter scales.

Voltages were read to three decimals with a 0-3 volt scale voltmeter, provided with a switch for selecting any one cell voltage. To prevent the voltmeter pointer following the "voltage fluctuation" across the cells, during pulsing at rates below 40 cps, which would result in inaccurate voltage readings, a switching arrangement was provided so that the cells could be switched to a steady direct current charging source at 2.4 amperes for the duration of the meter readings.

While it is realized that voltages read to three decimals with an ordinary d'Arsonval voltmeter movement would be subject to suspicion

as to the absolute accuracy of the third decimal, values were nevertheless read as closely as possible, with the aid of the magnifying glass placed over the scale. The prime purpose of the voltage readings was to ascertain the point of completion of charge, based on the fact that voltage across the cell reaches a maximum at the end of charge and thereafter decreases slightly. Thus, even though the absolute magnitude of voltage may have been slightly in error, the method used enabled the operator to determine quite closely the end-of-charge point, inasmuch as the previously mentioned voltage decrease was easily discernible. It is well to note that a "set of voltage readings", as taken periodically during the finishing rate charge, consisted of three separate readings, one for each cell. In switching the voltmeter from cell to cell, its pointer momentarily swung toward zero, during the switching period, so that for each cell voltage reading, the pointer always approached its steady state position from the same direction. Any lost motion was therefore always in the same direction.

Time was reckoned by an electric timer connected to be energized automatically whenever the cells were connected to either the charge or discharge circuit.

Temperature of each cell was obtained by means of a Fahrenheit thermometer sealed into the filling cap, with the thermometer bulb immersed in the cell electrolyte.

Temperature of the evolved gas was obtained with a Centigrade thermometer inserted into the gas collecting vessel of one cell, by way

[illegible]

of a pilot or sample temperature determination. The investigators felt that elimination of thermometers in the other two gas collecting vessels was justified, since the three vessels were grouped closely together, and therefore subject to essentially the same changes in ambient temperature, which proved to be the major factor in determining gas temperature. Further, the two investigators were required to make 11 readings within the space of about 30 seconds every 6 minutes, so that elimination of all unnecessary readings was highly desirable.

Evolved gas from each cell displaced an equivalent volume of water from a calibrated glass vessel. The level of the remaining water in each vessel was accurately determined periodically with a cathetometer.

3. Reverse Current Protection

Inclusion of this device in the charging circuit was necessary to prevent accidental discharge of the cells through the generator armature, in the event of a power failure. The reverse current relay (Figure 14) was connected to be normally energized, through a disc rectifier; thus, the relay was energized only when current was flowing in the proper (charging) direction. Voltage to operate this relay was obtained from the IR drop across a resistance in series with the charging circuit. If, for any reason, the cells commenced to discharge through the charging circuit, the rectifier prevented current flow through the relay coil and caused the contacts to drop out. Deenergization of this relay simultaneously opened the cell circuit, stopped the electric timer clock, and shut down the motor-generator set, after which manual resetting was necessary.

of a list of names of persons who were present at the time of the investigation. The investigation was conducted by the Department of the Interior, and the results of the investigation are set forth in the report of the Department of the Interior, dated June 1, 1906.

Twelve has been sold at a price of \$1.00 per bushel, and the balance of the crop is now in the hands of the Government.

The relay was energized only when current was flowing in the motor circuit. Voltage to operate this relay was obtained from the 110 volt source. A resistance of 20 ohms was connected in series with the relay coil. The relay contacts were connected in parallel with the motor circuit.

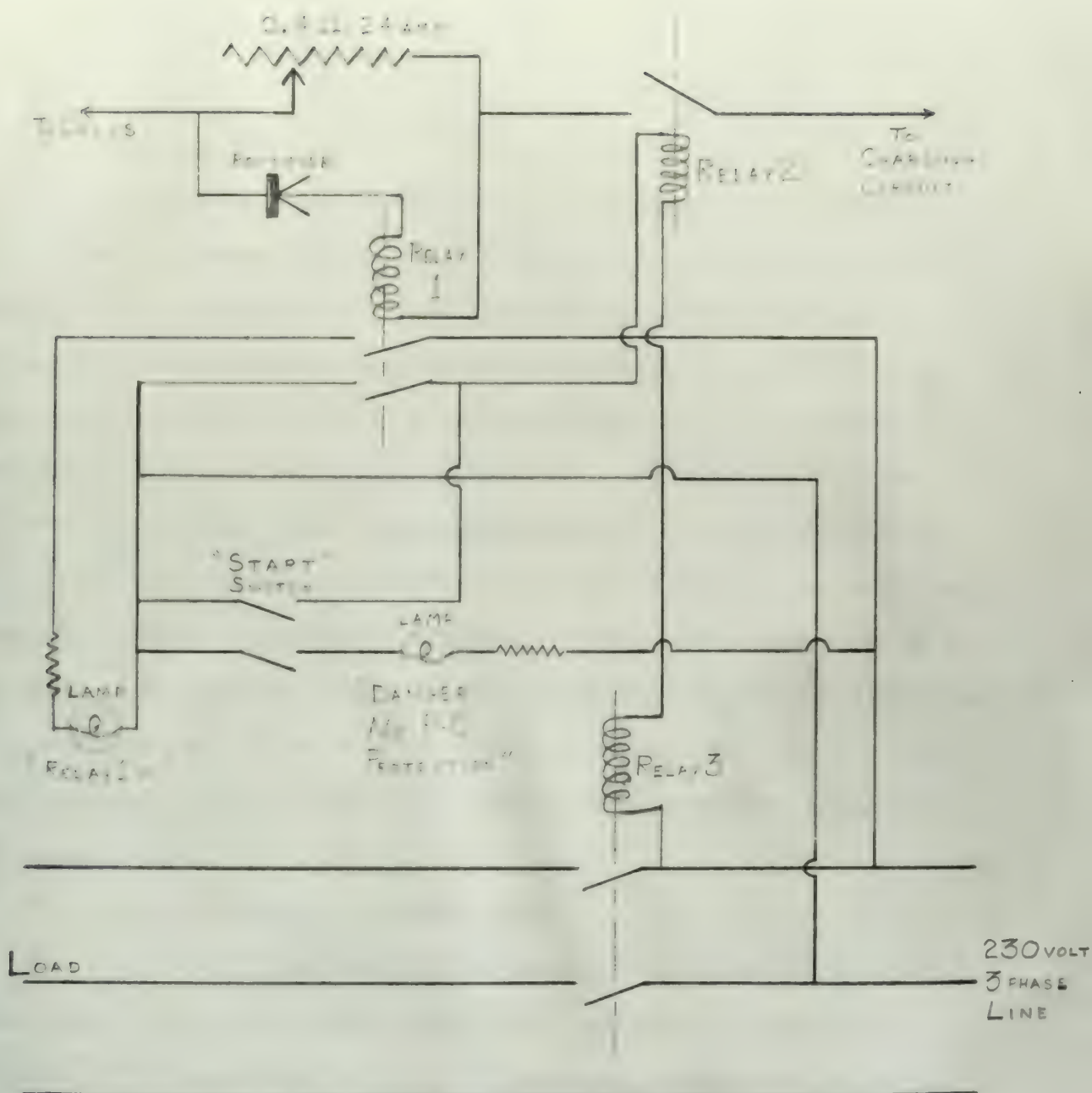


Figure 14. Reverse current relay detail.

4. Power Supply

In order to insure a minimum of interruptions or disturbances to the charging current and auxiliary apparatus (clock, motor driven timer switch, etc.), a primary power source of high capacity was desired. The system used was the largest capacity system available in the laboratory, viz., the 230 volts, 3 phase, a. c. distribution system. A transformer provided 115 volts, single phase, where needed. An oversized motor-generator set provided a stable source of charging current. This source sufficed for both the steady charging currents and the 0.5 to 8 cps pulsating direct current for charging. Alternating current for charging, from 20 to 100 cps, was supplied by a motor driven alternator, with the motor connected to a "Ward-Leonard" generator system for speed control. 400 cps alternating current was obtained from a 1.8 KVA voltage regulated, motor driven, 400 cps alternator.

5. Detailed Description of Components

The overall provisions of the experimental setup have been set forth above, followed by several explanatory paragraphs on the salient features of the apparatus. A detailed, functional description of component parts follows.

Referring to Figure 15, note that three basic arrangements of the apparatus were required. Figure 15A shows the arrangement where only steady direct current was required for charging. This arrangement was employed for the starting rate charge during every cycle, and for the finishing rate charge during the control cycles (q.v.), and was the basic arrangement, to

which modifications were made as necessary for pulsating charges, as shown in Figure 15B and C.

The generator was a 2 KW, 32 volt, 62.5 ampere machine, driven by a 15 HP induction motor, and sufficient in capacity to show negligible regulation under the relatively light charging load. Some ripple of 540 cps was discernible in the output of this machine, but the percentage of ripple voltage was negligibly small.

Two parallel connected rheostats were employed, supplementary to the current regulating ballast tubes, as previously described. Rheostat values were 4 ohms and 25 ohms, the former serving as a coarse control, the latter as a fine control.

The voltmeter arrangement for metering individual cell voltages was described above. Switch details are shown in Figure 16. Separate leads were run from the terminals of this switch direct to the actual terminals of each cell, rather than to the "battery" terminals, to eliminate any IR drop inherent in the latter terminals, by virtue of their carrying either charge or discharge current.

The reverse current protective device and the bank of Amperite current regulating tubes were previously described in this appendix. Of the Amperite ballast tubes it is worth saying that they were procured in three sizes, viz., 2-A-10, 5-A-10, and 9-A-10, having nominal current ratings of 0.2, 0.5, and 0.9 amperes, respectively. Suitable combinations of these tubes in parallel gave the various desired charging current values.

In Figure 15B, the galvanometer current metering circuit, a cur-

in Figure 17B and C.

The presenters are a 2 Hz, 20 volt, 500 Hz square wave, shown in a 10 Hz duration window, and exhibited in Figure 17B and 17C. The wave is shown under the relatively high magnification. The figure is 10 Hz and the frequency is the subject of this section, but the frequency is 10 Hz and the wave is relatively small.

The presenters are shown in Figure 17B and 17C. The wave is shown in a 10 Hz duration window, and exhibited in Figure 17B and 17C. The wave is shown under the relatively high magnification. The figure is 10 Hz and the frequency is the subject of this section, but the frequency is 10 Hz and the wave is relatively small.

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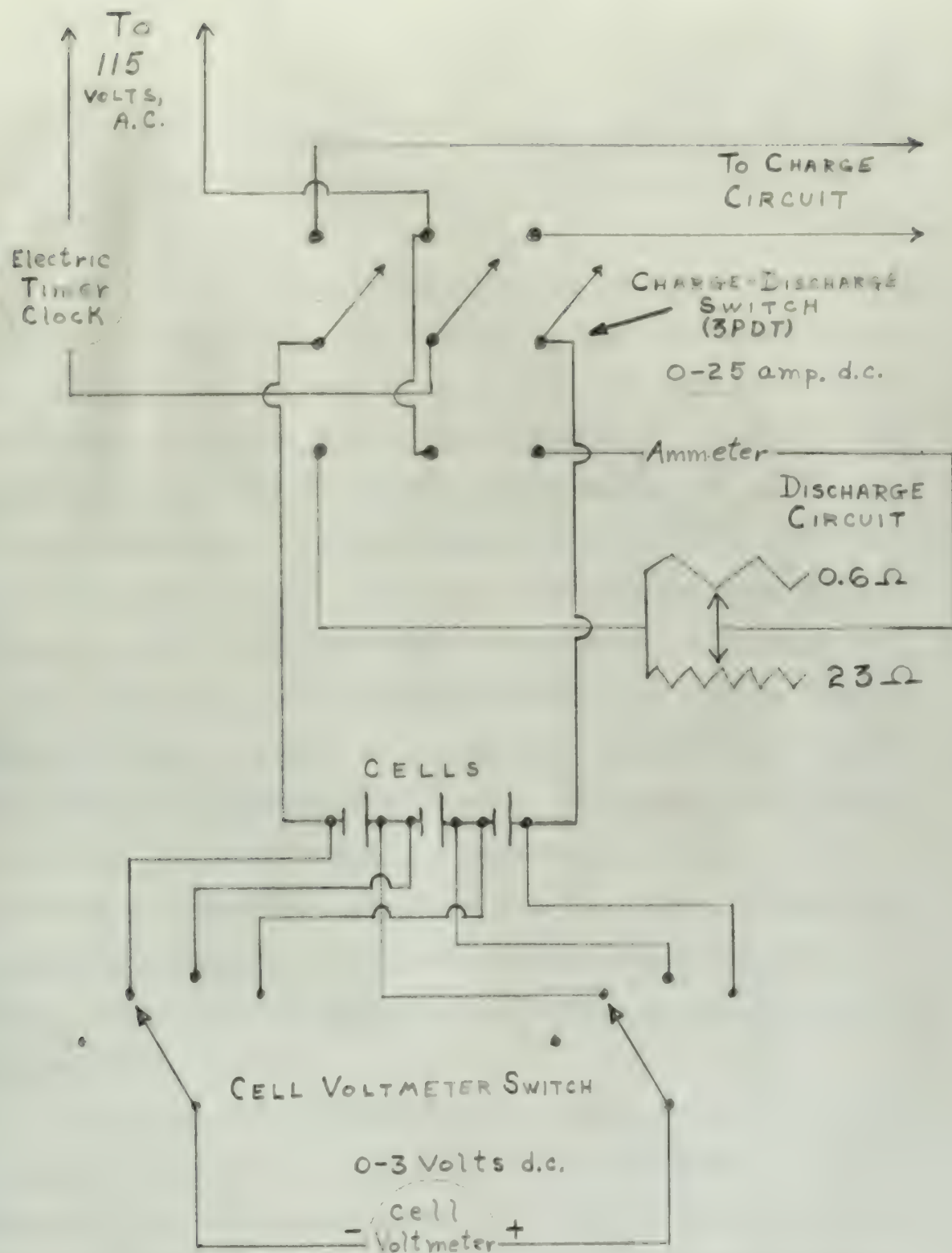


Figure 16. Cell voltmeter switch detail.

rent selector switch, a motor driven, cam operated pulser, or timer switch, an additional bank of Amperite tubes, and additional rheostats have been added.

The galvanometer circuit detail is shown in Figure 17. The galvanometer and its purpose have been described earlier. The associated relay was controlled from the galvanometer position, and permitted switching of the galvanometer from the cell charging circuit to the reference current circuit, while maintaining continuity of these circuits. The reference current circuit consisted of a source of direct current at 250 volts (obtained from a 5 KW generator, tandem coupled to the main induction motor and 32 volt generator set), a 2.4 ampere bank of Amperite tubes, a 0-3 ampere ammeter, two parallel connected rheostats of about 25 ohms each, and sufficient series resistors to limit the current to the desired value. Current in this circuit was maintained at 2.4 amperes. The galvanometer scale was not calibrated in amperes. Rather, the pointer was set to give zero deflection when the galvanometer was connected in the reference current circuit; then the galvanometer was switched into the charging circuit, and charging current adjusted to again give zero deflection, corresponding to 2.4 amperes average current.

The current selector switch, shown in detail in Figure 18, enabled the operator, in one switching operation, to choose 2.4 amperes of (1) steady current, or (2) pulsating current, at a frequency generated by and preset in the motor driven timer switch. The purpose of the steady current source was described under "Mensuration".

The heart of the low frequency, pulsating current generating device was the motor driven, cam operated timer switch shown in Figure 19.

that solution which, a water solution, was applied below, to form a film, on an etched base of insulating paper, and additional thicknesses were then added.

The polymerization of the monomer is shown in Figure 1. The polymerization was carried out in a glass tube, the temperature of which was controlled from the polymerization position, and provided with a thermometer from the wall showing directly the reference current. The reference current, while maintaining constancy of these elements. The reference current circuit consisted of a source of direct current of 200 volts (obtained from a 5 KV generator, limited through to the main induction motor and 20 volt generator set), a 1.5 ohm resistor of 1000 ohms, a 10-1 ohm resistor, two potentiometers of 1000 ohms each, and a 10-1 ohm resistor. The potentiometers were used to limit the current to the desired value. The reference current was maintained at 0.1 ampere. The polymerization was not carried in water. Indeed, the polymer was not in this case. The solution was the polymerization was conducted in the reference current circuit; this the polymerization was carried into the changing circuit, and changed current adjusted to again give the desired current. 1.5 ohm resistor circuit.

The current solution which, shown in detail in Figure 1, consisted of the solution, in an etching position, to which 1.5 ohm resistor of (1) steady current, or (1) galvanic current, as a frequency provided by the current in the water from the water. The current in the steady current source was described under "Memorandum".

The body of the low frequency, following current, described in the text, was the water from, was applied from which shown in Figure 1.

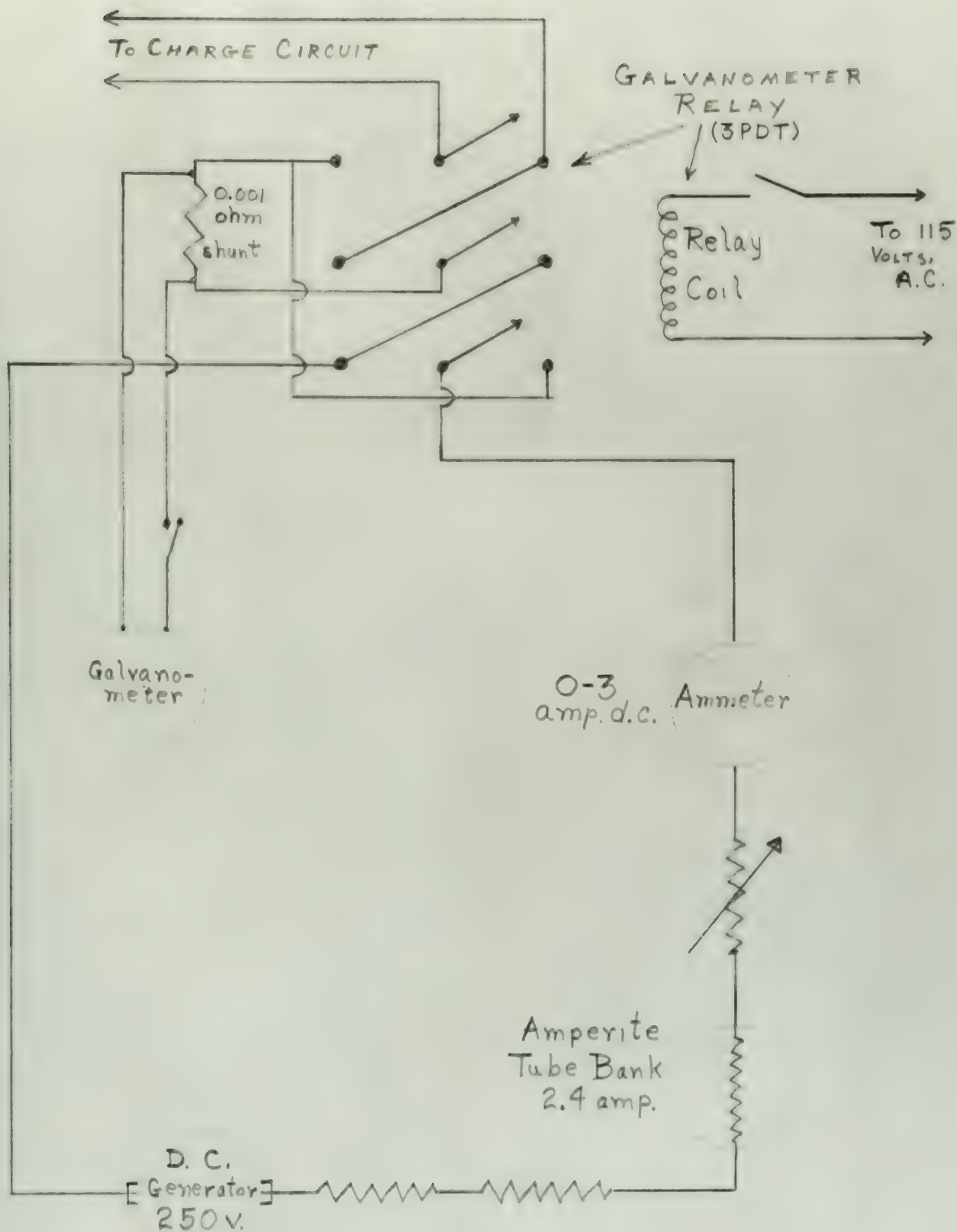


Figure 17. Galvanometer circuit detail.

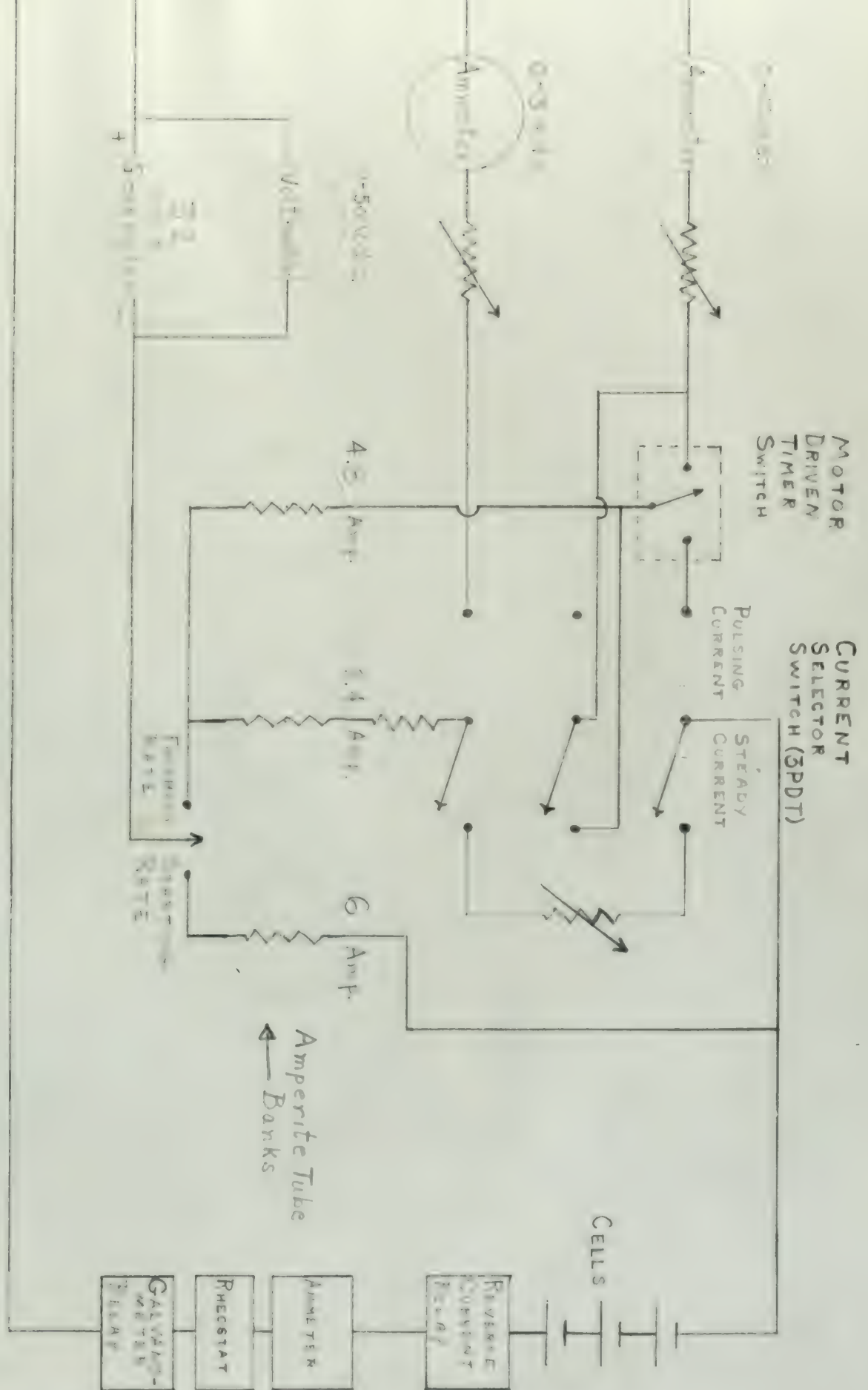


Figure 18. Current selector switch detail.

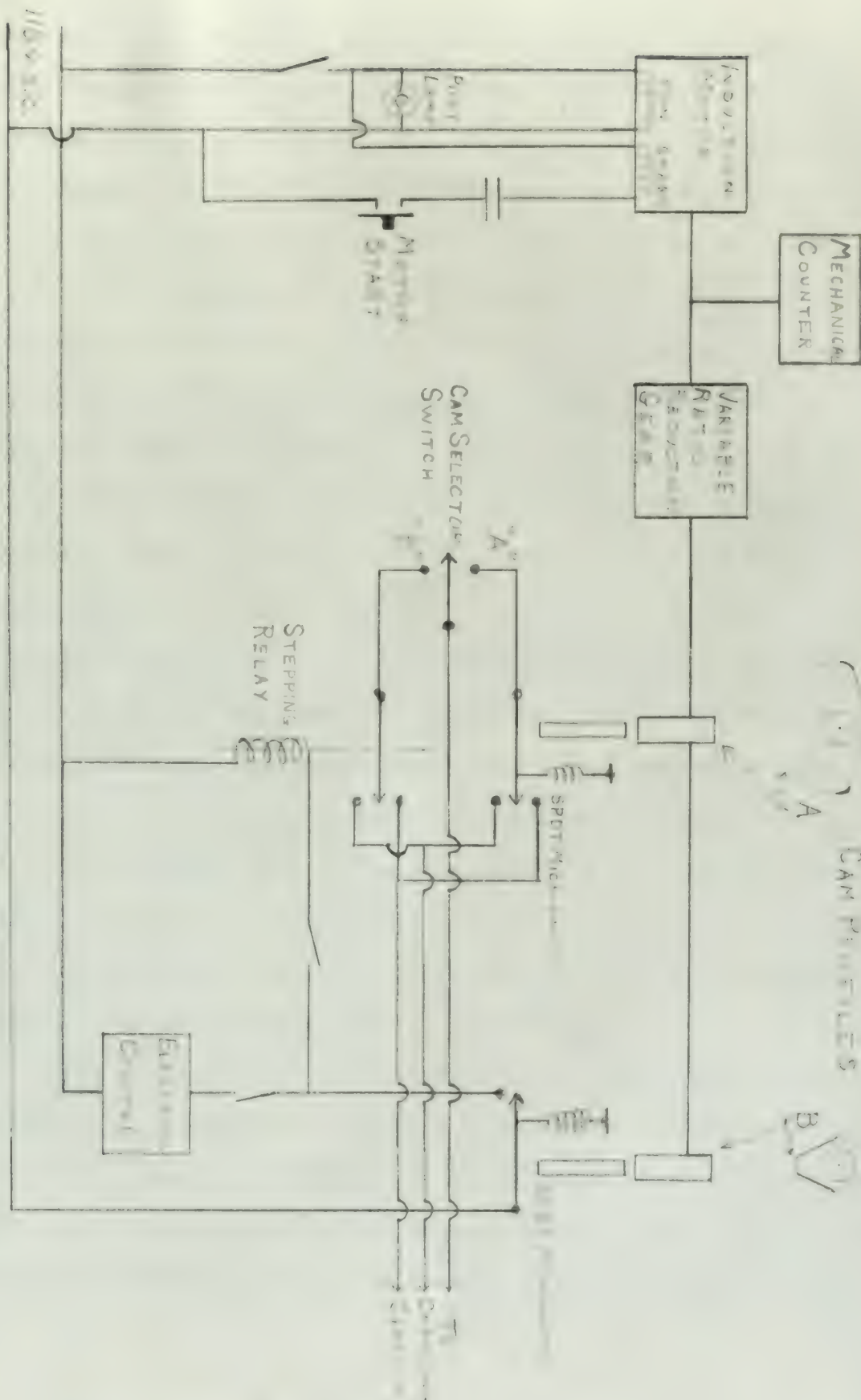


Figure 19. Motor driven timer switch.

Comprising this was a fractional horsepower induction motor driving a simple cam through a variable ratio gear train. The cam actuated a microswitch once during each revolution. The microswitch in turn energized the coil of a locking type stepping relay, with single pole, double throw contacts. The stepping relay construction was such that its contacts threw to one position or the other with each energization of the coil, and remained locked in that position until a subsequent energization of the coil. In one position the circuit to the cells was completed through the 4.8 ampere Amperite bank. In the other, the cell circuit was opened, and the Amperite tubes were switched to a rheostat and ammeter, leading back to the generator. Thus, the cells alternately received either 4.8 amperes or no current, giving an average current of 2.4 amperes, as required. The speed range of the cam permitted a pulsating current frequency range of about 0.2 to 5 cps. It was discovered that the stepping relay arrangement was unsuitable for frequencies above about 2 cps, however, so that for the runs at 3 and 7.8 cps, an additional microswitch and cam were installed, the microswitch, with single pole, double throw contacts, being substituted circuit-wise for the contacts of the stepping relay. The cam operated this microswitch every 180° of rotation, extending the frequency range of the device to an upper limit of about 10 cps.

The resistance of an Amperite ballast tube varies with temperature in much the same manner as does that of an ordinary incandescent lamp, except that the thermal time constant of the Amperite tube is longer. Due to this thermal characteristic of the Amperite tubes, it was found necessary to cause the desired value of current to flow through them continuously in

[illegible]

order to realize optimum current regulation. Thus, the 4.8 ampere bank of Amperite tubes was switched alternately from the cells to the previously mentioned rheostat and ammeter circuit back to the generator, the rheostat being adjusted to give an ammeter reading of 4.8 amperes, so that 4.8 amperes flowed through these Amperite tubes continuously. A similar arrangement was provided for the 2.4 ampere bank of Amperite tubes, used for obtaining steady current for purposes of voltage metering. The current selector switch connected this bank either into the cell circuit, or to a rheostat and ammeter circuit returning to the generator. Whenever the 2.4 ampere circuit was switched to the cells for a voltage reading, the motor driven timer switch contacts were short circuited, so that for this position of the current selector switch, the associated 4.8 ampere bank of ballast tubes was continuously connected to its rheostat and ammeter return circuit, independent of the timer switch.

In Figure 15C, the variable frequency alternator, thyatron rectifier bank, and associated Amperite tube bank have replaced the motor driven timer switch of Figure 15B, with other features remaining essentially the same. At frequencies of 40 cps and greater it was unnecessary to use the galvanometer for metering of current, since ordinary d'Arsonval type meters gave satisfactory results at these frequencies. Three General Electric type FG-95 thyatron tubes connected in parallel were used to half-wave rectify the alternator output. No attempt was made to utilize the unique characteristics of the thyatron tubes. Indeed, any rectifier of suitable current carrying capability would have served the purpose. The one outstanding advantage of the particular thyatrons employed was their immediate availa-

[illegible]

bility to the investigators. At the frequencies involved here (20 cps and above) it was found unnecessary to consider the thermal delay inherent in the Amperite tubes, and no auxiliary switching arrangement was provided for the purpose.

6. Gas Collecting Apparatus

The gas collecting apparatus consisted of 3 one gallon, round glass jugs, one connected to each cell and, through a pressure equalizing flask, to an over-flow reservoir, by rubber tubing, as shown in Figure 20. Gas from a cell displaced an equal volume of water from its associated jug. Pressure within each jug was reduced to atmospheric prior to each reading, by matching the water levels of the jug and its equalizing flask. Height of liquid in the jug was read to 0.01 cm with a cathetometer. Cross sectional areas of the jugs were sufficiently linear over the operating range to permit the use of a constant term in computing volume of water displaced, as, for example, 200 cc per cm. Gas volume was temperature corrected to 27° C.

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provided for the purpose.

The gas collecting apparatus consisted of 3 one liter round-bottomed flasks, connected in series by rubber tubing, as shown in Fig. 1. The gas from a cell displaced an equal volume of water from the first flask. The gas was then passed through a series of wash bottles, and finally into a gasometer, where it was collected over water. The gasometer was graduated in cubic centimeters, and the volume of gas collected was read off from the scale. The gas was then passed through a series of wash bottles, and finally into a gasometer, where it was collected over water. The gasometer was graduated in cubic centimeters, and the volume of gas collected was read off from the scale.

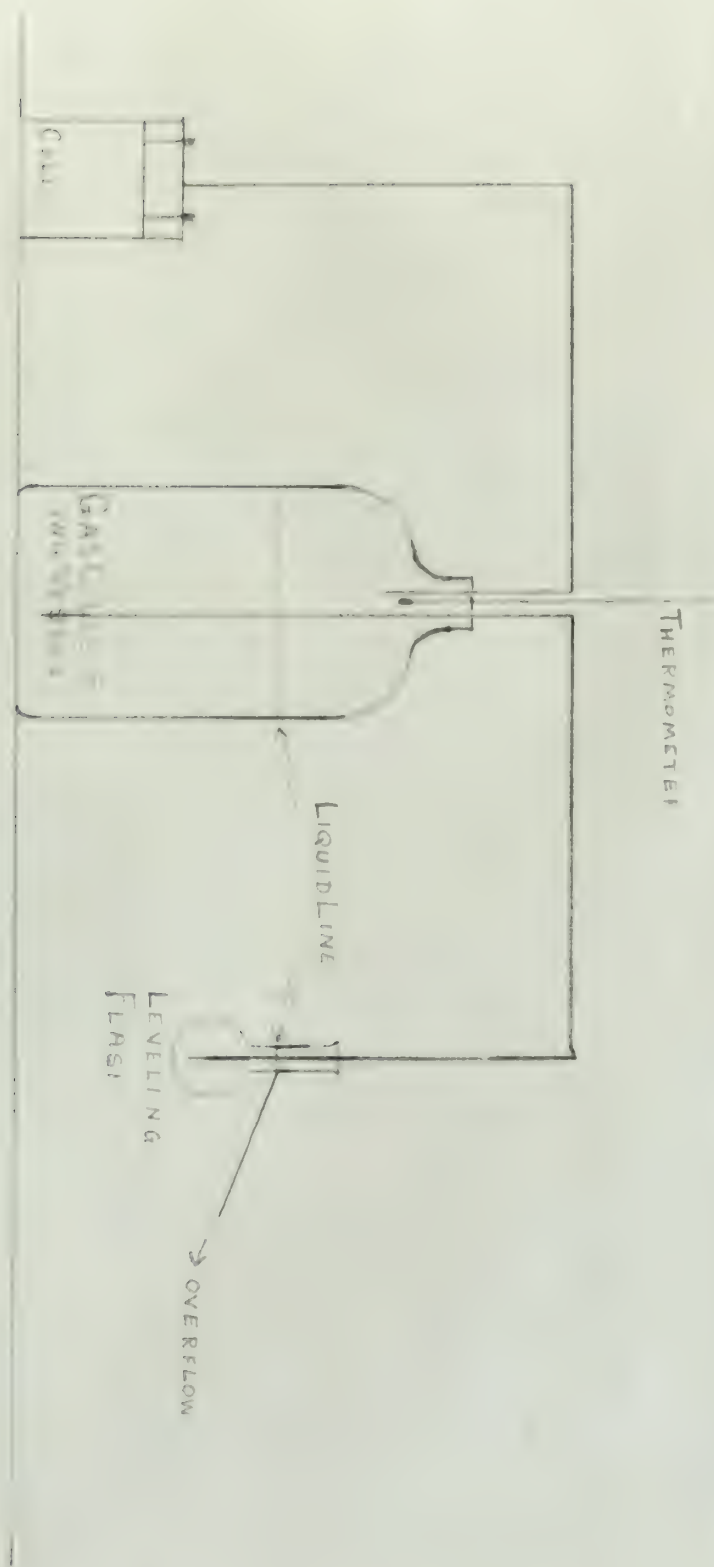
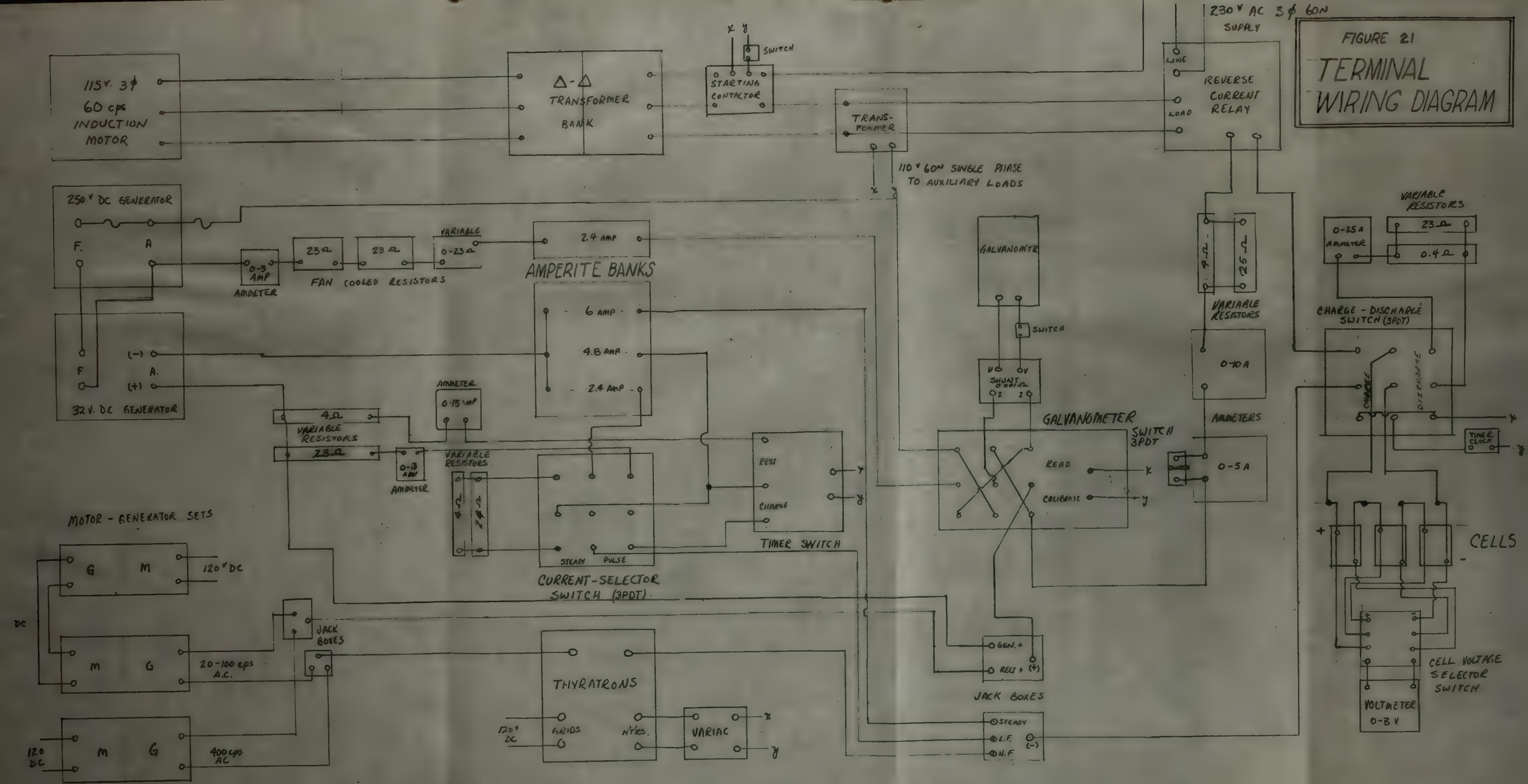


Figure 20. Gas collecting apparatus.

FIGURE 21
**TERMINAL
 WIRING DIAGRAM**



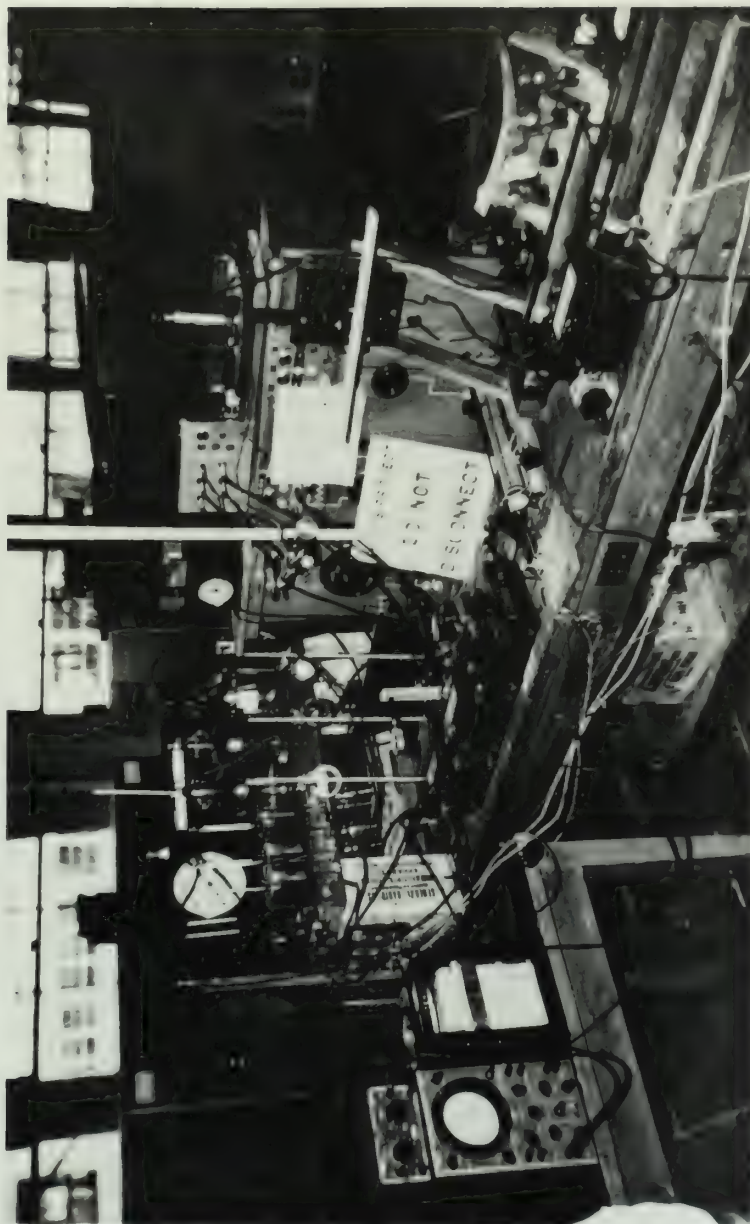


Figure 22-A. View of setup.

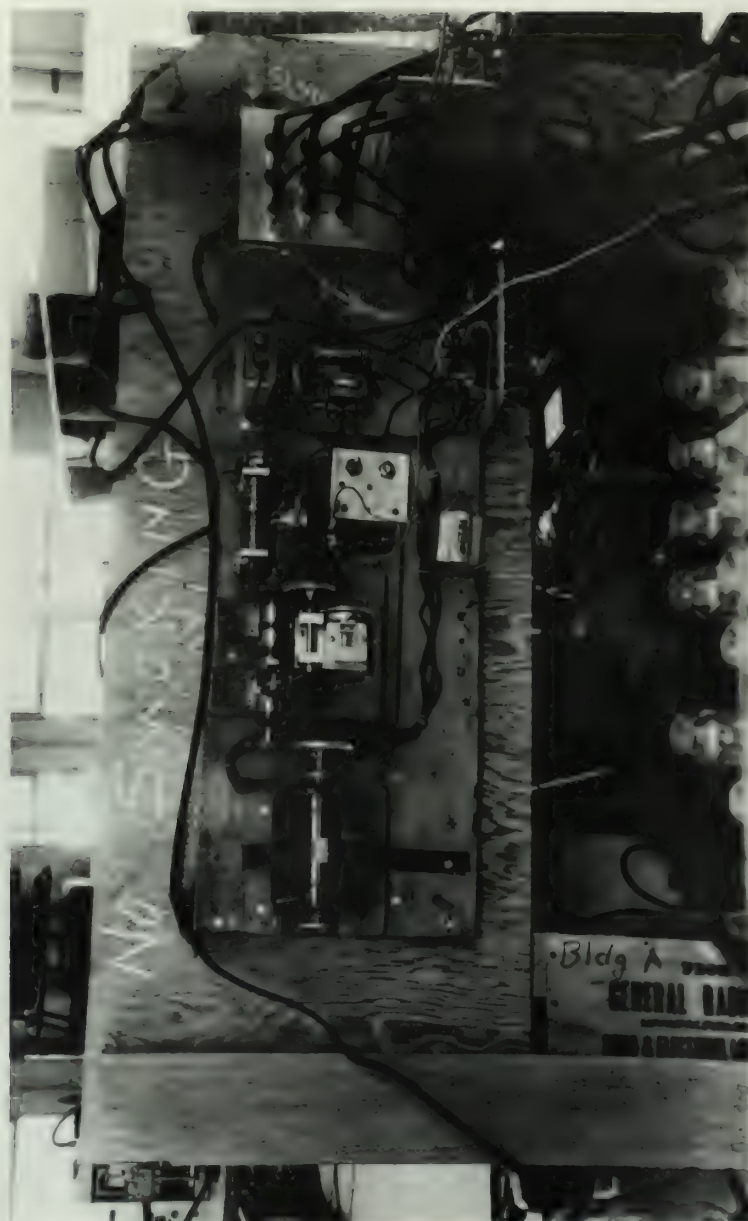


Figure 22-B. View of motor driven timer switch.



Figure 22-C. View of Amperite banks and motor-generator set.

APPENDIX B

SAMPLE CYCLE ANALYSIS SHEET

Discharge

Current (I_d) - Constant at 15 amperes throughout discharge.
 Mean Voltage (V_{md}) - Time weighted mean voltage, from voltage readings made every 6 minutes throughout discharge.
 Duration (t_d) - Duration of discharge in hours.
 Ampere-hours (Q_d) - Product of I_d and t_d .
 Energy (W_d) - Product of I_d , V_{md} and t_d .

Charge - Starting Rate

Current (I_s) - Constant at 6.02 amperes throughout starting rate charge.
 Mean Voltage (V_{ms}) - Time weighted mean voltage, from voltage readings made every 12 minutes throughout starting rate charge.
 Duration (t_s) - Duration of starting rate charge in hours.
 Ampere-hours (Q_s) - Product of I_s and t_s .
 Energy (W_s) - Product of I_s , V_{ms} and t_s .

Charge - Finishing Rate

Current (I_f) - Constant average value throughout finishing rate charge.
 Mean Voltage (V_{mf}) - Time weighted mean voltage of finishing rate charge.
 Duration (t_f) - Duration of finishing rate charge in hours.
 Ampere-hours (Q_f) - Product of I_f and t_f .
 Energy (W_f) - Product of I_f , V_{mf} and t_f .

Gas

Height (h) - Difference in height in centimeters of water in gas collecting vessel at beginning of finishing rate charge and end of finishing rate charge.
 Area (A) - Cross sectional area of gas collecting vessel in square centimeters.
 Volume (V') - Volume of water displaced from gas collecting vessel during finishing rate charge - product of A and h .
 Temperature (T) - Gas temperature at end of finishing rate charge, °C.
 Volume (V) - V' corrected for T to a datum of 27°C, or 300° Kelvin (Centigrade, absolute).

APPENDIX 2

TABLE 1. ANALYTICAL DATA

Continued

<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days. Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>	<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>
<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>	<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>
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<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>	<p>Location of 10 square kilometers of water in the area of the lake, from which the water was collected. The water was collected from the lake every 2 weeks. The water was collected at intervals of 10 days.</p>

Volume of gas per - V/Q_f
ampere-hour of finish-
ing rate charge.

Volume of gas per - V/W_f
watt-hour of finish-
ing rate charge.

Total ampere-hours (Q_c) $Q_s + Q_f$
of charge.

Total watt-hours (W_c) $W_s + W_f$
of charge.

Efficiency, am- (γ_Q) Q_d/Q_c
pere-hour.

Efficiency, watt- (γ_W) W_d/W_c
hour

Volume of gas per unit
 weight of liquid
 $\frac{V}{W}$

Volume of gas per unit
 weight of liquid
 $\frac{V}{W}$

Total weight of
 gas
 $W + W_g$

Total weight of
 gas
 $W + W_g$

Efficiency, or
 percentage
 $\frac{W_g}{W}$

Efficiency, or
 percentage
 $\frac{W_g}{W}$

DATE	2/19/53	CYCLE	A-2	FRIC.	0.5		
ITEM	UNITS	1	12	13	14		
I_d	AMP.	15.00	→				
V_{md}	VOLTS	1.9370	1.9344	1.9325			
t_d	HRS	0.8	→				
Q_d	AMP.-HR.	12.00	→				
N_d	WATT-HR.	23.244	23.213	23.262			
I_s	AMP.	6.02	→				
V_{ms}	VOLTS	2.2434	2.2458	2.2613			
t_s	HRS	1.503	→				
Q_s	AMP.-HR.	9.049	→				
W_s	WATT-HR.	20.298	20.820	20.460			
I_f	AMP.	2.397	→				
V_{mf}	VOLT	2.4570	2.4473	2.4774			
t_f	HRS	1.85	1.75	1.75	$\langle 3.286 = t_c \rangle$		
Q_f	AMP.-HR.	4.434	4.195	4.195			
N_f	WATT-HR.	10.894	10.266	10.393			
R	CM.	3.70	3.00	3.02			
A	CM ²	200	195	191.5			
V'	CM ³	740.00	585.00	578.33			
T	°C	26.9	→				
V	CM ³	740.25	585.19	578.52	634.05		
V/Q_f	CM ³ /A.H.	166.95	139.50	137.91	148.12		
V/W_f	CM ³ /W.H.	67.95	57.00	55.66	60.20		
Q_c	AMP.-HR.	13.482	13.243	13.243	13.323		
W_c	WATT-HR.	31.192	30.586	30.853	30.877		
η_e	%	89.00	90.61	90.61	90.07		
η_w	%	74.52	75.89	75.40	75.27		

SAMPLE CALCULATION

APPENDIX C

RAW DATA

Laboratory data sheets for all cycles are included in this appendix in chronological order. Dates, cycle numbers, and frequencies are as follows:

<u>Frequency</u>	<u>Cycle Numbers</u>	<u>Date</u>
0.5	A2	2/19/53
1	A4	3/2/53
3	A8	3/23/53
7.5	A11	4/1/53
20	A5	3/4/53
40	A3	2/25/53
100	A9	3/25/53
400	A10	3/26/53
Steady	A1	2/18/53
"	A6	3/5/53
"	A7	3/9/53
"	A12	4/8/53
"	B1, B2	4/28/53
"	B3, B4	4/29/53
"	B5	4/30/53

The final data sheet lists the meters and recorders used.

RECEIVED

1941

RECEIVED

RECEIVED

RECEIVED

DATE	DESCRIPTION	AMOUNT
5/10/51	AS	0.5
5/15/51	AS	1
5/20/51	AS	2
5/25/51	AS	7.8
5/30/51	AS	100
6/5/51	AS	100
6/10/51	AS	100
6/15/51	AS	100
6/20/51	AS	100
6/25/51	AS	100
6/30/51	AS	100
7/5/51	AS	100
7/10/51	AS	100
7/15/51	AS	100
7/20/51	AS	100
7/25/51	AS	100
7/30/51	AS	100
8/5/51	AS	100
8/10/51	AS	100
8/15/51	AS	100
8/20/51	AS	100
8/25/51	AS	100
8/30/51	AS	100
9/5/51	AS	100
9/10/51	AS	100
9/15/51	AS	100
9/20/51	AS	100
9/25/51	AS	100
9/30/51	AS	100
10/5/51	AS	100
10/10/51	AS	100
10/15/51	AS	100
10/20/51	AS	100
10/25/51	AS	100
10/30/51	AS	100
11/5/51	AS	100
11/10/51	AS	100
11/15/51	AS	100
11/20/51	AS	100
11/25/51	AS	100
11/30/51	AS	100
12/5/51	AS	100
12/10/51	AS	100
12/15/51	AS	100
12/20/51	AS	100
12/25/51	AS	100
12/30/51	AS	100

RECEIVED

1ST TEST CYCLE - STEADY (1000)

[illegible]

18 Feb 1953

1st Test case

свази

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	12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Test Run # 3 - notified 40 cps a.c.

25 Feb. 1953

	I	T	V	G	T	V	G	T	V	G	
0851	2.4	Commenced "topping off" charge.									
	↓	#11			#12			#13			
0853		2655			2685			2695			
0857		2673			2720			2738			
0900		2695			2720			2738			
0902	2.4	67 2695			68.5 2720			70 2738			
		Secured t.o. charge									
0911	0	2222			2220			2231			man. cut.
0914	0	2220			2208			2211			
0920		2200			2196			2205			
0922	Start dual run										
0925	14.99	1960			1960			1977			
0926	14.99	1975			1960			1977			
0927	CORR =	1958			1949			1960			
0935	10.01	1940			1932			1940			
0944	CORR =	1921			1917			1922			
0950	15.00	1902			1896			1902			
0956	↓	1875			1870			1875			
1002		1839			1834			1834			
1008		74 1781			75 1780			78 1779			
		Secured charge									
1010	Commenced starting rate change.										
1012	6.0										
1012		2102			2098			2104			
	Elect. ht	29.43			29.44			29.36			
	Pull line	28.59			28.56			28.64			

Test Run # 3 - notified 40 cps a.c.

25 Feb. 1953

Time	I	T	V	G	T	V	G	T	V	G	Time	Notes
1024	6.0		2166			2165			2179			Bottle top bits.
1036	6.0		2200			2199			2213			4911 4922 4922
1048	6.0		2222			2224			2240			
1100	6.0		2245			2250			2261			
1112	6.0		2268			2274			2283			
1124	6.0		2300			2301			2317			
1136	6.0		2335			2339			2350			
1139	6.0		2343			2345			2360			
1140	0	stopped charge										
1143	Start	2.40	2348	3305	84	2350	3207	85	2361	33.68		
1155	CORR =		2270			2273			2291			40
1207	-003		2285			2288			2300			40
1219	2.397		2305			2308			2320			40.5
1231	↓		2334			2330			2347			40.5
1243			2400			2350			2412			40
1255			2528	32.45		2544	32.63		2560	32.71		39.7
1301			2576	32.09		2585	32.07		2610	32.72		40
1307			2592	32.33		2609	31.84		2622	31.62		40
1313			2602	31.70		2615	31.40		2631	31.71		
1319			2608	30.64		2632	30.75		2641	30.72		40
1325			2612	30.13		2658	30.78		2641	30.71		40
1331			2614	29.55		2640	29.62		2648	30.01		40
1337			2616	29.01		2640	29.12		2652	29.77		40
1343			2615	28.46		2640	29.30		2652	29.71		40
1349		91	2615	27.73	94	2640	29.77	95	2650	29.02		40.5
1355			2614	27.27		2638	29.58		2648	28.55		40.5
1401		92	2608	26.18	96	2637	26.45	96	2646	28.04		40

1406 stopped charge.

4th Test Curve 2 1/2 KPa 30



		I	T	U	L	T	U	L	T	U	L	GT
1150		2.40		26.0			1712			2.100		
1156				26.0			2.100			2.100		
1160			72	26.0		73	26.0		75	26.0		
1165				26.0			2.100			2.100		
1170				26.0			2.100			2.100		
1175				26.0			2.100			2.100		
1180				26.0			2.100			2.100		
1185	Slipped clamp			26.0			2.100			2.100		
1190		1169		1.991			1.991			1.991		6
1195				1.980			1.980			1.980		5
1200				1.970			1.970			1.970		2.5
1205				1.960			1.960			1.960		5.5
1210				1.950			1.950			1.950		9
1215				1.940			1.940			1.940		6
1220				1.930			1.930			1.930		6
1225				1.920			1.920			1.920		6
1230	Slipped clamp		79	1.910		81	1.910		83	1.910		3
1235												
1240	I											
1245	6.0			2.120			2.121			2.120		
1250	6.0			2.102			2.102			2.100		
1255	6.0			2.196			2.198			2.111		
1260				2.111		87	2.120			2.237		
1265				2.100			2.101			2.201		
1270				2.111			2.111			2.201		

Time	Loc		I	T	U	T	U	L	T	U	L	GT
1400			6.0	80	2.111	80	2.111	81	2.111			
1410	Slipped		↓		2.110		2.110		2.110			
1420	Slipped											
1430	Slipped											
1440	Slipped											
1450	Slipped		2.111				2.111		2.111	2.111	2.111	
1460												
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5 March 6th Test Cycle Steady current

		I	T	V	G	T	V	G	T	V	G	T	V	G	T	V	G
1049	Commence 1st, 2nd	2.40	77	26.2		77	26.2			26.2			26.2				
1050				26.5			26.72			26.4			26.4				
1100				2.68			26.93			27.05			27.05				
1106				2.667			26.93			27.05			27.05				
1108				2.447			26.92			27.05			27.05				
1109	Stop change																
1110	Start divide	14.99															
1111			8	79.93		82	19.95		84	20.08							
1116				20.01			19.97			20.05							
1122				19.86			20.80			19.7							
1128				1.965			19.58			19.67							
1134				1.948			19.42			19.52							
1140				1.922			19.20			19.2							
1146				1.899			19.2			19.00							
1152				1.860			18.6			18.6							
1158	Stop			18.19			18.14			18.18							
1200	Commence SR	6.0	86.5			88			90								
1203		6.0		210.9			210.7			211.9							
1212		6.0		214.7			214.5			216.1							
1224		6.0		219.2			218.2			219.9							
1236				2.1			2.1			2.1							
1248				2.2			2.2			2.2							
1260				2.3			2.3			2.3							
1272		6.0	86	217.9		87	22.0		88	22.0							
1324		6.0	87	231.2		89			91	23.0							

6TH CYCLE

5 March

STEADY CURRENT

		I	T	V	G	T	V	G	T	V	G	T	V	G	T	V	G
1330	the 7th Stopped	6.0	87	2.2			2.2			2.2			2.2				
1335	the 7th Stopped	2.40		2.26			2.26			2.26			2.26				
1340				2.22			2.22			2.22			2.22				
1356				2.16			2.16			2.16			2.16				
1408				2.15			2.15			2.15			2.15				
1420				2.335			2.335			2.335			2.335				
1422				2.19			2.19			2.19			2.19				
1440				2.483			2.483			2.483			2.483				
1456				2.572		31.75	2.572	32.51		2.612	32.15	27.4					
1458	Stopped																
1500	the 7th	2.40															
1506				2.581			2.581	32.77		2.612	32.15	27.4					
1514				2.609	30.76		2.628	31.20		2.640	31.87						
1522				2.615	30.76		2.621	31.46		2.634	31.23	28.8					
1528				2.615	30.76		2.641	30.90		2.651	30.75	28.8					
1534				2.615	30.76		2.641	30.90		2.651	30.75	28.8					
1540				2.621	29.70		2.648	29.87		2.664	29.78	28.8					
1546				2.618	29.70		2.647			2.663	29.78	28.8					
1552				2.620	29.70		2.647			2.663	29.78	28.8					
1558				2.617	29.70		2.646	29.70	72	2.662	29.70	28.8					

Note - Cathodic protection was removed after reading on level of cathodic protection was taken. Level was found to be 2.11.

Δ max 12.9

100

-2.9

30.35

1.86

-2.5

16.1

18.6

155.3

33.89

9 March 1958

Steady current test

7th cycle

Signal Time	Remarks	I	T	V	G	T	V	G	T	V	G	GT
1047	Commenced by 1st	74	74	74	74	74	74	74	74	74	74	74
1051				2.432			2.465			2.672		
1100				2.640			2.676			2.687		
1105				2.652			2.680			2.699		
1110				2.658			2.684			2.700		
1115				2.660			2.689			2.700		
1120				2.662			2.690			2.708		
1125				2.662			2.695			2.710		
1130				2.664			2.695			2.717		
1135	Stopped 1st stage											
1140	2nd stage (12AH) 14.55											
1145	(10)			1972			1996			2004		
1150				1989			1993			1995		
1155				1971			1985			1978		
1200				1960			1947			1959		
1205				1948			1930			1940		
1210				1932			1912			1927		
1215				1925			1887			1891		
1220				1880			1857			1802		
1225				1877			1813			1818		

9 March 1958

Steady current test

7th cycle

Ratios 11-48.37
12-48.45
13-48.45

Signal Time	Remarks	I	T	V	G	T	V	G	T	V	G	GT
0	1220	6.0										
2	1222			2108			2123			2114		
4	1226			2133			2129			2141		
6	1232			2120			2155			2163		
24	1249			2170	2170	2170	2189	2186	2186	2203	2210	
30	1256			2216			2218			2231		
50	1310			2210			2215			2225		
60	1320			2210			2228			2229		
1112	1312			2210			2228			2229		
1120	1314			82	2.327		86	2.322		87	2.346	
1128	1318	Reached 1.0 second change								87	2.360	
1130	1350	Reached 6 sec rate 240			2170	2170	2170	2170	2170	2170	2170	
1135	1404			84	2170		87	2170		88	2170	
1140	1416				2286		2270			2282		
1145	1422				2305		2306			2320		2318
1150	1430				2328		2327			2341		
1155	1450				2348		2360			2379		
1200	1504				2370		2435			2455		
1205	1510				2570		2614			2691		180
1210	1520				2586	2154	2601	2176		2617	2170	28.0
1215	1530				2600	2170	2619	2141		2633	2140	28.0
1220	1540				2649	20.61	2627	20.70		2642	20.70	27.7
1225	1545				2642	20.08	2630	20.45		2640	20.45	27.8
1230	1550				2649	29.55	2649	29.90		2652	29.97	27.7
1235	1555				2650	28.99	2640	29.38		2654	29.41	27.6
1240	1600				2650	28.45	2641	28.83		2651	28.93	27.6

7 March

STEADY CURRENT

7th cycle

Signal Time	Remarks	I	T	V	G	T	V	G	T	V	G	GT
2-10	1604	240		2610	27.81		2640	28.12		2657	28.40	27.7
2-15	1610	240		2621	28.10		2640	28.14		2657	28.91	27.8
2-20	1615	240		2619	28.14		2640	28.11		2658	28.94	27.8
2-25	1620	240		2621	28.14		2640	28.11		2658	28.94	27.8
2-30	1625	240		2621	28.14		2640	28.11		2658	28.94	27.8
2-35	1630	240		2621	28.14		2640	28.11		2658	28.94	27.8
2-40	1635	240		2621	28.14		2640	28.11		2658	28.94	27.8

23 MARCH 1953

TEST CYCLE #8

34200

				I	T	V	G	T	V	G	T	V	G	T	V	G	T
1048	Commenced	topping off		24	81	2613		81	2662		83	2666					
1103						2626			2660			2673					
1111						2632			2662			2678					
1116						2632			2662			2675					
1121						2634			2662			2676					
1126						2634			2664			2676					
1128	Stopped change	Asphalt															
1150-2	0			1498													
	1.5		2.21	8	81	18.5		88	1891		90	20.2					
	6		2.25			1990			1983			1997					
	12		6			1975			1965			1978					
	18					1958			1941			1960					
	24					1939			1921			1941					
	30					1918			1901			1920					
	36					1895			1883			1898					
	42		6			1862			1852			1863					
1200	48		3			18			18			182					
1240																	
1240	00																
	04					3117		31	3120		32	2126					
	12					3146			3134			2150					
	24					3180			3177			2177					
	36					2204			2197			2220					
	48					2224			2224			2242					
									32.19			32.52					
									48.25			48.25					
												43.21					

P2711 4.4

48.25

48.25

43.21

23 March

Test Cycle #8

34200

				I	T	V	G	T	V	G	T	V	G	T	V	G	T
1340	60	Continued	rate	6.0		22.5	32.4		2248	32.52		2266	32.52				
	1:12	Stiller	from		92	2273		94	2274		94	2295		33.7°			TVL =
	1:26	Stiller			91	2270		93	2312		94	2334					2224
	1:28	Stopped change	Asphalt			2336			2319			2338					
1410-2	0:00	Resumed change		2.4	91			93			94						
	0:12					2255			2254			2273		3.00			TVL =
	0:24					2266			2265			2283					TVL =
	0:36					2282			2283			2301					TVL =
	0:48				91	2306		94	2304		94	2321		3.00			TVL =
1510-2	1:00					2337			2331			2350					TVL =
	1:12					2350			2347			2362		3.00			TVL =
	1:25					2355			2354			2376					TVL =
	1:36					2364	31.6		2376	31.15		2393	31.15				TVL =
	1:42					2375	31.4		2389	30.50		2402	30.95	31.7			TVL =
	1:48					2390	29.91		2402	30.51		2416	30.1	31.6			TVL =
	1:54					2399	29.2		2411	29.1		2422	29.6	31.6			TVL =
	2:00					2392	29.41		2402	29.1		2424	29.57	31.6			TVL =
	2:06					2385	28.22		2402	29.15		2426	29.4	31.0	3.00		TVL =
	2:12					2384	28.15		2402	29.1		2428	29.4	31.0			TVL =
	2:18					2384	27.25		2402	29.1		2428	29.4	31.0			TVL =
	2:24					2382	26.64		2399	28.14		2428	29.4	31.0			TVL =
	2:30					2382	26.64		2399	28.14		2428	29.4	31.0			TVL =
	2:31	Stopped change															

25 MARCH 1953

TE: 1111 4

105 2/100

			I	T	V	G	T	J	G	T	V	G	C/T	f
19.0	0	Commenced 1 p.m.	2.70											
	0-09				2663		0	2658		80	2706			
	0-15				2660			2658			2706			
	22	Loose voltage. comm. 11.4.12			2650			2672			2703			
	28				262			2672			2703			
		Adjusted in change												
19.6	0	Comm. back	1877	81			84			85				
	0-05				198			1992			2006			
	0-6				1997			1990			2000			
	12				1979			1972			1983			
	18				1900			1900			1903			
	20				1939			1934			1942			
	24				1920			1902			1901			
	28				1900			1900			1900			
	30				1900			1900			1900			
19.0	0-01	Started discharge			1523			1798			1804			
19.1	0-00	Started charge	60	82			86			87				
	0-05													
19.1	0-01	Comm. to higher comm.												
19.1	0-01	Comm. to higher comm.												
	0-15				2188			2186			2181			
	0-24				2202			2203			2220			
	0-36				2222			2235			2241			
	0-48				2247			2252			2266			

[illegible]

26 March 1953

Test run # 10

400 N

			I	T	V	G	I	T	V	G	I	T	V	G
1032	00	1p 41	2.4		2677				2678				2686	
	04				2639				2679				2690	
	06				2642				2680				2692	
	12				2643				2680				2694	
	18				2645				2679				2693	
→	21				2643				2678				2692	
	23				2682									
	24	Secured												
1156	0	Comm. discharge												
	0-2		14.99	83	2006		85	2002		87	2014			
	06				2003			1998			2007			
	12				1996			1978			1988			
	18				1965			1959			1966			
	24				1946			1939			1948			
	30				1922			1918			1923			
	36				1899			1890			1898			
	42				186			1854			1859			
1144	48	Stop discharge			1812			1804			1810			
1145	0	Start change 60												
	0-3			86	2102		88	2100		89	2111			
	0-12				2148			2146			2162			
	24				2185			2187			2200			

26 March, 1953

Test run # 10

400 N

Time			I	T	V	G	I	T	V	G	I	T	V	G	GT	(11)	+ 32.652
0:36			6.00		2211 (48.11)				2214 (48.17)				2225 (48.17)				
0:48					2235				2239				2252				
1:00					2258				2263				2280				
1:12				86	2246		88	2239		89	2268						2252
1:24					2322	2273		2328	22505		2345	2249					
1:26	Stopped	41.704									89	2352					
1312	0-00	Resumed		2.40		3273			32505				3248				
	0-02	Run			2248				2259				2272				
	0-12	0.2			2265				2269				2273				
	0-24	0.4		2.40	2280				2282				2299				
	0-36	0.6			2298				2302				2317			2500	
	0-48	0.8			2311				2321				2338				
	1-00	1.0			85.5	2349		88	2351		89	2363					
	1-12	1.2				2387			2397				2412			3500	
	1-24	1.4				2452			2497				2518				
	1-36	1.6				2570			2592				2611				
→	1-42	1.7				2593	3135		2608	3105		2626	3100	2877			
	1-48	1.8			87	2593	3012	90	2621	3000	90.5	2637	3055	2877	3500		
	1-54	1.9				2603	3041		2628	3012		2643	3012	286			
	2-00	2.0				2606	2995		2632	2960		2648	2959	283			
	2-06	2.1				2608	2940		2636	2907		2652	2911	284			
	2-12	2.2				2605	2884		2636	2851		2650	2855	282	3500		
	2-18	2.3			→	2610	2838	→	2639	2796		2654	2803	288			
	2-24	2.4				2610	2788		2636	2746	→	2655	2752	289			
	2-30	2.5				2610	2736		2636	2700		2655	2696	290	3500		
	2-36	2.6				2605	2693		2636	2652		2651	2646	289			
	2-37	Stop change															

1 April 1953 Cycle #11 24~

				I	T	V	G				T	V	G		
0805				0		2121						2137			
0807	00	in out 77m off		2.4											
	06					2643						2694			
	08				72			73			75				
	12					2660						2702			
	14					2668						2706			
	24					2664						2703			
	24:07	Amused			75			76.5			78.5				
		Commence discharge													
0837	00				14.99										
	01				↓	1980						1991			
	02:30					1984						1993			
	06					1981						1974			
	12					1963						1959			
	18				77	1945		79			81	1951			
	24					1926						1928			
	30					1905						1908			
	36					1879						1880			
	42					1840						1839			
	48				80	1768		83			85	1762			
0921	0	Commence change		600											
	05					2124						2135			
	12					2152						2164			
	24					2188						2202			

1 April 1953 Cycle #11 7 1/2 ~/sec

T. 4-15.0

				I	T	V	G	T	V	G	T	V	G	GT	f
1003	0-36	Coal many small roots		6.0		2210	(48.14)	2210	2219	(48.24)		2230	(48.28)		
	0-40					2211			2241			2256			
1027	1-00			V	83	2262		85	2267		87	2275			
	1-12				83	2290	32.2	85	2300	32.52	86	2312	32.38		
	1-24				82	2325		84.5	2338		85.5	2349			
	1-28	Step 1.467 hrs.				2346			2352			2364			
1102	0-00	Amused		2.4		2244			2248						7.76
	0-02			↓	82	2241		85	2248		86	2259			
	0-12					2248			2273			2293			
	0-24					2281			2270			2301			
	0-36					2303			2307			2311			7.79
	0-48					2324			2329			2338			
	1-00				82	2358		86	2358		87	2363			
	1-12					2415			2411			2415			
	1-24					2519			2536			2524			
	1-36					2580			2618			2614			
	42					2582	30.88		2621	30.74		2627	30.83		
	1-48					2593	30.45		2628	30.16		2638	30.1		
	1-54					2603	29.86		2634	29.85		2643	29.96	7.78	
	2-00					2628	29.4		2639	29.25		2643	29.45	27.9	7.75
21	2-06	Bad connection				2641	29.01	→	2646	28.66		2657	28.94	27.9	
	2-12					2610	28.47		2640	28.13		2645	28.48	28.0	
	2-18					2607	27.98		2640	27.57		2644	27.85	28.0	
24	2-24					2608	27.47		2639	27.04	→	2650	27.47	28.0	
	2-30					2607	26.15		2639	26.45		2644	26.93	28.0	
	2-36					2604	26.46		2604	25.91		2644	26.46	28.0	7.80
	2-42	2-42													

Voltage supply 0.054 per inch & down 0.016

8 APRIL 1953

TEST CYCLE #12

STEADY

			I	T	"	G	T	"	G	T	"	G	T	"	G	T
0840	Commenced Ramping up		2.4													
0	0.05		↓	59	2.720		58.5	2.750		61	2.759					
	05				2.720			2.752			2.762					
	14				2.721			2.755			2.762					
	19				2.720			2.755			2.762					
	24			62.5	2.719		62.5	2.751		67	2.761					
0909	0 Comm. disk		11.99													
	01.5	3.2			1.969			1.959			1.977					
	06	2.2	↓		1.962			1.948			1.966					
	12				1.946			1.932			1.948					
	18				1.928			1.916			1.932					
	24				1.908			1.897			1.912					
	30				1.894			1.871			1.885					
	36				1.852			1.840			1.853					
	42				1.800			1.782			1.790					
0957	47.5	3.2			1.600			1.620			1.605					
	48	As needed		71			72	1.60		74.5						
								— Low cell —								
0159	0 Comm. change		6.00													
	02		↓		2.110			2.113			2.112					
	18				2.169			2.171			2.181					
	24		↓		2.199			2.201			2.212					
	36				2.223			2.230			2.241					
	48			76	2.260		74	2.259		79	2.281					

Note: L.V.L. = 1.05

8 APRIL 1953

TEST CYCLE #12 CTD

STEADY

			I	T	"	G	T	"	G	T	"	G	T	"	G	T
1059	1-00	Continue SR	6.00		2.276	48.25		2.274	48.25		2.279	48.25				
	1-12		↓	78	2.276	48.46	80	2.319	48.45	81	2.322	48.45				
	1-24		↓	79	2.344		81	2.358		82	2.367					
	1-26	As needed SR														
1126	0	Start SR	2.40													
	0-03				2.264			2.268			2.281					
	0-13		↓		2.277			2.280			2.293					
	0-24				2.287			2.296			2.306					
	0-36				2.305			2.312			2.323					
	0-48				2.325			2.330			2.342					
	1-00			81	2.352		83	2.360		83.5	2.369					
	1-12				2.401			2.410			2.416					
	1-24				2.498			2.527			2.525					
	1-36				2.579	31.91		2.610	31.33		2.616	31.42	25.7			
	1-42				2.591	31.05		2.614	30.89		2.623	31.04	25.6			
	1-48				2.600	30.65		2.626	30.38		2.641	30.59	25.6			
	1-54			84	2.606	30.13	87	2.640	29.92	87	2.647	30.16	25.6			
	2-00				2.610	29.72		2.644	29.33		2.652	29.65	25.5			
	2-06				2.612	29.27		2.643	29.86		2.653	29.79	25.6			
	2-12				2.614	28.75		2.643	28.31		2.656	28.70	25.8			
	2-18		→		2.615	28.29		2.643	27.75		2.656	28.19	25.7			
	2-24			87	2.612	27.77	91	2.642	27.15	91	2.656	27.59	26.0			
	2-30				2.619	27.32		2.642	26.64		2.655	27.18	26.0			
	2-31-05	Secured.														

28 April

0.1 0.1

29. 1

[illegible]

28 April 1964 22 Sh. S. current.

[illegible]

29 Apr 1953 Cycle 83 STANLEY

					I	T	"	S	T	72	G	T	V	G	67
0828	0-00	Commenced Appr; 87	24				2.662								
	05				725		2.662		74	2699		76	2720		
	12						2.679			2722			2721		
	18						2.679			2702			2702		
	21						2.679			2702			2721		
0830	0-00	Comm lunch	14.99				1.98								
	01				75		1.98		78	1969		79.5	1.987		
	05						1.982			1974			1987		
	10				76		1.960		77	1954		80	1.96		
0841	00	Start change	2.4				32.26	32.26		32.24	32.25			32.27	
	05						2.97			2.96			2.97		
	12						2.211			2.209			2.220		
	24						2.232			2.233			2.242		
	36						2.261			2.260			2.275		
	48				77		2.321		80	2.325		81	2.340		
0941	1-00						2.473			2.526			2.533		
	1-06						2.619	31.97		2.655	32.35	26	2.662	32.61	26.4
	1-12						2.644	31.42		2.681	31.91		2.672	32.22	26.0
	1-18						2.656	30.87		2.695	31.27		2.700	31.67	26.1
	1-24						2.659	30.6		2.685	30.71		2.701	31.17	26.0
	1-30						2.657	29.80		2.685	30.13		2.699	30.64	26.0
	1-36	stopped			82		2.657	29.25		2.682	29.51		2.691	30.09	26.2
									85			86			

Cycle 84 29 April 1953 STANLEY

					I	T	"	G	T	72	G	T	V	G	67
10-7	1	Start & change			14.98			[42.18]				[42.20]		[42.22]	42.26
	01					82	2.00		85	2.01		86	2.02		
	05						2.007			1.998			2.00		
10-7	12					85	1.98		86	1.98			1.983		
10-7	1	Start change			24			29.16				29.1			29.2
	01						2.00			2.09			2.08		
	12						2.20			2.201			2.212		
	24						2.224			2.228			2.23		
	36						2.25			2.255			2.26		
	48					81	2.27		84	2.273		85	2.28		
80	1-01						2.273			2.272			2.27		
	1-06						2.64	26.6		2.678	26.15		2.67	26.7	27.0
	1-12						2.651	26.1		2.680	26.40		2.67	26.7	27.0
	1-18						2.641	25.11		2.67	25.13		2.67	25.13	27.0
	1-24						2.64	25.4		2.672	25.1		2.672	25.1	27.0
	1-30						2.64	25.5		2.671	25.20		2.67	25.2	27.1
	1-36						2.672	25.97		2.67	26.5		2.67	26.4	27.1
	1-42	stopped			85				87			88			

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